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Teacher change during a professional development program for implementation of the Science Writing Heuristic approach

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DEDICATION

To the memory of my mother Faye Williams and to my father E.W. “Corny” Williams, for the love and support they have given me.

To my loving wife Susan Andrews, and our wonderful children Heather McMichen and Joshua Williams, for the sacrifices they made as I took classes, conducted research, analyzed data and wrote this dissertation. Without their love and support this work would not have been completed.

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ABSTRACT

One of the critical issues in reforming science education is that despite nearly a century of efforts to promote inquiry as a means for students to learn science, teachers often do not effectively implement inquiry-based instruction. In order to provide inservice teachers with assistance in making the necessary changes in their practice by developing new skills, knowledge and beliefs, a variety of professional development programs have been created.

This study was conducted to examine a group of teachers for changes in their practice and beliefs as they implemented the Science Writing Heuristic (SWH) approach to inquiry instruction while receiving long-term in-class support. In addition, the relationship between the teachers' beliefs and the extent that their practice changed was also explored.

The results of this study suggest several emerging themes. Although a number of barriers relating to the teachers' skills, knowledge and beliefs were identified, two of the three teachers did make progress towards more effective implementation of the SWH approach. The teachers' beliefs appeared to play a significant role in the effective implementation of inquiry and the extent that their practice changed. The time that the teachers' invested into enacting the SWH approach in their classroom also appeared to play an important role in the extent to which change in practice occurred. Finally, the results of this study suggest that professional development may better help meet current educational goals if the focus is on assisting well-trained teachers in refining their practice rather than attempting major changes in those who lack the basic skills, knowledge and beliefs required to implement inquiry effectively.

CHAPTER 1. INTRODUCTION

During the past four decades efforts to reform science education have focused on students learning science by engaging in activities similar to the inquiry methods scientists use (DeBoer, 1991). Through the use of inquiry as a means to learn, students are envisioned as being able to "describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge and communicate their ideas to others" (National Research Council, 1996, p. 2). While great emphasis is placed on actions that students should take, teachers are acknowledged to play a crucial role as "initiating, conducting and maintaining a sense of inquiry as a part of instruction in science is a highly complex form of teaching" (Flick & Dickinson, 1997, p. 1). Over the past thirty years numerous research studies have provided a broad description of the many practices that teachers must effectively implement in order for students to learn. While the use of inquiry has shown promise in helping students in a number of areas, including understanding of science concepts and development of process skills (Bransford, 2000; Haury, 1993; Shymansky, Hedges, & Woodworth, 1990; White & Frederiksen, 1998), numerous studies have indicated that many teachers do not effectively implement inquiry in their classrooms (Harms & Yager, 1981; Pasley, Weiss, Shimkus, & Smith, 2004; Stake & Easley, 1978).

The lack of effective implementation of inquiry is due in part to a number of barriers that teachers face (Anderson, 1996). Some of these barriers are beyond teachers' direct control, including mandatory curricula and testing that emphasizes coverage of too much material and recall of factual information. However, other barriers result from factors that teachers have some degree of control over, including lack of the skills and knowledge required to facilitate students' use of inquiry. In addition, certain teachers' beliefs including that students learn

best from the textbook and a commitment to covering large amounts of material to prepare students for the next level of schooling, create barriers to the effective implementation of inquiry.

Professional development programs have been developed to assist teachers in developing the skills, understanding and beliefs needed in order to more effectively implement inquiry-based instruction. However, research has shown that professional development has not always been viewed as effective by teachers and does not always result in major changes in teachers' practice (Guskey, 1986; Loucks-Horsley, Love, Stiles, Mundy, & Hewson, 2003). Historically, most professional development programs have consisted of workshops that are short in duration, based on training models where the goal is to replicate effective behaviors, and do not connect with other programs or to the teacher's classroom work (National Commission on Teaching & America's Future, 1996; Loucks-Horsley et al., 2003; Richardson & Placier, 2001). Reviews of the professional development literature continue to demonstrate that most programs are ineffective at creating significant change in teachers' practices (Guskey, 2002). Based on the overall poor results of professional development, it is argued in the *National Science Education Standards* (referred hereafter as the *NSES*) (National Research Council, 1996) that "reforming science education requires substantive changes in how science is taught, which requires equally substantive change in professional development practices at all levels" (p. 5).

Recently, studies have begun to elucidate factors necessary for change in teachers' practice to occur during professional development, including inservice work that occurs in the teachers' classrooms where they can engage in concrete teaching tasks with their students (Anderson & Mitchner, 1994; Darling-Hammond & McLaughlin, 1995; National Research

Council, 1996). Providing the opportunity for teachers to work in the 'real world' context of their classroom can also assist in changing their beliefs because "where the focus is the actual work of each teachers' own students – one's values and beliefs are encountered at every turn" (Anderson, 1996, p. 68). Other important factors include providing teachers training in the reform-based strategies, modeling of the approaches by an experienced mentor and constructive feedback on their implementation (Anderson & Mitchner, 1994; National Research Council, 1996).

Taking into account the crucial role of language in learning, and the potential benefits of writing as a way to learn in particular, the Science Writing Heuristic approach (SWH)(Keys, Hand, Prain, & Collins, 1999) was originally developed as an inquiry-based alternative to traditional laboratory reports. However, as the pedagogical practices and underlying learning theories are congruent with those that promote learning, teachers are also urged to use the SWH approach in all aspects of their instruction, not just when engaging students in laboratory exercises. Emphasizing the role that argument plays in developing scientific knowledge, a key outcome with use of the SWH approach is that students are encouraged to make connections among their observations, claims and evidence. Research suggests that use of this approach results in many positive student outcomes including improved conceptual understanding of science concepts, promotion of metacognitive thought about laboratory activities, reflection about the knowledge generated, and improved understandings of the relationship between questions, claims and evidence (Hand, Wallace, & Yang, 2004; Hohenshell, Hand, & Rudd, 2002; Keys et al., 1999; Keys, Yang, Hand, & Hohenshell, 2001; Rudd, Greenbowe, Hand, & Legg, 2001; Wallace, Hand, & Prain, 2007). However, consistent with the research literature, studies have indicated that student achievement is

affected by the extent to which the instructor effectively implements the SWH approach (Omar, Hand, & Greenbowe, 2002; Omar, 2004). As a result, a number of professional development programs have been developed to assist teachers in making changes in their practice needed in order to more effectively implement the SWH approach.

Purpose

While there is anecdotal evidence from previous studies that teachers have changed their practice in order to more effectively implement the SWH approach, this has yet to be examined and described in a research study. Thus, this study was conducted in order to examine implementation of the SWH approach by three teachers in a small, rural school district while receiving long term, in-class professional development support with a primary purpose of determining what changes occurred in their pedagogical practices. Two secondary purposes of this study were to determine what changes occurred in the teachers' beliefs about teaching and learning, and to elucidate any relationships between their practices and beliefs that may have affected the extent to which improvement in practice occurred.

The particular form of the professional development utilized in this study also provides a unique context. While most professional development activities in previous studies of the SWH approach have come directly from university researchers, in this study a retired science teacher who remains an active part of the science education research community provided support. Thus, while it is not the purpose of this study to examine the effectiveness of the professional development program itself, this unique context does provide an opportunity to examine teacher change when implementing inquiry strategies within an atypical professional development setting.

Research Questions

While inquiry approaches to the teaching and learning of science have generally proven to help students meet many of the goals of science education, including the learning of science with understanding, numerous studies have suggested that the use of inquiry in the classroom is not as widespread and effective as many involved in science education would like. While there are many reasons for this, one area that has received much attention is the inability of many teachers to effectively implement inquiry teaching due to lack of the needed pedagogical skills and knowledge, beliefs that are not congruent with the use of inquiry, or both. There seems to be agreement on the need to provide appropriate professional development experiences for inservice teachers such that they can learn how to more effectively implement inquiry in the classroom. In order to examine the changes in both the pedagogical practices and beliefs about teaching and learning of a group of three teachers implementing the SWH approach, this study is guided by the following research questions:

1. What changes occurred in teachers' pedagogical practices, and beliefs about teaching and learning, as they implemented the SWH approach while receiving support in a professional development program?
2. What was the relationship between the teachers' beliefs about teaching and learning and changes in their practice as they implemented the SWH approach while receiving support in a professional development program?

Dissertation Organization

Chapter two reviews the relevant literature in order to provide a justification for conducting this study and a theoretical perspective allowing for the interpretation of the research results. This review is divided into the following main sections detailing: the use of

inquiry in the classroom, the teacher's role in implementing inquiry-based instruction, efforts to change teacher practice, the effects of teachers' beliefs on their actions and the Science Writing Heuristic approach to using inquiry in the classroom.

Chapter three provides a description of this study's design, including the context in which the study took place and a justification for the design, based on the current literature in research methods. This chapter is divided into three main sections detailing: the context of this study, the justification for the particular qualitative methods used to investigate the research questions, and the qualitative research design of this study.

Chapter four presents the case study results regarding each teachers' pedagogical practices, beliefs about teaching and learning, and possible changes in practice and beliefs. This chapter is divided into three main sections detailing the results for each of the three teachers.

Chapter five serves to discuss the results of this study in terms of how the teachers' pedagogical practices, and beliefs about teaching and learning, may have both changed and interacted to influence the extent to which effective implementation of the SWH approach occurred, as the result of participation in a professional development program. In addition, limitations to this study and possible implications are also discussed.

CHAPTER 2. LITERATURE REVIEW

Introduction

The purpose of this chapter is to review the relevant literature in order to provide a justification for conducting this study and a theoretical perspective allowing for the interpretation of the research results. This review is divided into the following main sections: the first examines the use of inquiry in the classroom, the second examines, the teacher's role in implementing inquiry-based instruction, the third examines efforts to improve teachers implementation of inquiry in the classroom, the fourth examines the effects of teachers beliefs on their actions and how this may impact efforts to change teachers pedagogy and the last examines the Science Writing Heuristic approach to using inquiry in the classroom.

In section one, a brief history of the calls for using inquiry in science education will be presented along with a discussion of the impact of constructivism on how inquiry is viewed in classroom science. The essential characteristics of inquiry in the classroom will be reviewed along with studies suggesting the potential for positive effects on students' outcomes when using inquiry-based instruction.

In section two, the critical role of the teacher in implementing inquiry-based instruction will be discussed including the many pedagogical practices, such as the use of effective questioning, that a teacher must use in order to effectively implement inquiry-based instruction. Research concerning the difficulties that many teachers have in using inquiry-based instruction will also be reviewed.

In section three, the need to promote changes in teachers' pedagogical practice in order for inquiry-oriented curricula to be effectively implemented is discussed along with results on previous efforts to create change in teachers. While many previous attempts to promote

changes in teacher practices required for effective inquiry did not result in long-term change, more recent efforts have provided insight into the conditions necessary for teachers to make changes in their practice and will be discussed in this section.

In section four, the relationship between teachers' beliefs and practice is reviewed. Efforts to distinguish between belief and knowledge are presented, followed by findings on beliefs relevant to this study. The ways that a teacher's beliefs may affect, or be affected by, their practice is then reviewed, followed by a discussion of the role of beliefs in teacher change efforts.

Finally, in section five, a novel approach to inquiry-based instruction, the Science Writing Heuristic approach, is described. The key components of this approach and the practices that have been found to influence the implementation of this approach are also discussed.

Inquiry

Historical calls for the use of inquiry in classrooms

Claims that teaching science as inquiry will lead to increased understanding of science and help students use their knowledge in real life situations have been the focus of reform efforts in science education for the past one hundred years (DeBoer, 1991). John Dewey (1910), often considered one of the first to promote the use of inquiry, argued that the predominant use of direct instruction in science teaching placed too much emphasis on the accumulation of information and too little on science as a way of thinking and an attitude of the mind. For Dewey, science was more than a body of knowledge to be learned, students could benefit from developing thinking and reasoning processes associated with the scientific process.

The 1957 launch of the Sputnik spacecraft renewed efforts to utilize inquiry in the classroom that still continue today, leading DeBoer (1991) to conclude that, "if a single word had to be chosen to describe the goal of science education during the 30-year period that began in the late 1950s, it would have to be inquiry" (p. 206). For example, Joseph Schwab (1960, 1966) argued that science operates as a type of inquiry where ideas are changed as the result of new evidence and that science teaching and learning should reflect this view of science. Thus, teachers should have students perform laboratory experiments first before being introduced to the formal explanation of scientific concepts (Karplus, 1975). Similar to the way in which scientists' operate, the students would use their evidence collected in the lab to develop explanations. In addition, he suggested that students should develop an understanding of what constitutes scientific knowledge and how it is produced.

Constructivism and inquiry

In addition to the arguments made by scientists and educators for the use of inquiry in the classroom, those who conceptualize learning as a constructivist practice have also promoted this view. Constructivism is based on a philosophical position that there is no objective reality independent of our way of knowing it (von Glasersfeld, 1983), and that individuals thus construct knowledge in an attempt to make sense of the world around them (Driver & Oldham, 1986). These constructions of reality are developed from our current perceptions and experiences, but also depend upon our prior knowledge (Simon, 1995), and are seen as tentative models that are always being tested against experience and are modified as needed (Driver & Oldham, 1986). Thus, constructivists' argued that knowledge is not transmitted directly from one knower to another, but rather is actively constructed by an individual (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Rather, learning is seen as a process of

conceptual change involving interaction between new and existing conceptions (Hewson & Hewson, 1984).

Research has shown that children develop ideas and beliefs about aspects of the natural world long before they are formally taught and that many of these ideas conflict with standard accepted scientific beliefs (Driver & Oldham, 1986). These alternative conceptions are firmly held and often persist despite teaching of the scientifically accepted correct concepts. In order to create conditions within which students are likely to change their conceptions, educators have suggested that teachers should provide experiences that create cognitive conflict between their existing alternative conceptions and the scientifically accepted concepts (Posner, Strike, Hewson, & Gertzog, 1982). The use of concrete experiences is seen as crucial in assisting students in changing their conceptions as Abraham (1998) asserted that "Laboratory activities should be used to introduce concepts so that students are given the opportunity to construct knowledge from their own experience and apply that knowledge to new situations" (p. 520).

However, many constructivists also argued that knowledge construction is also socially mediated; that is, "understandings are constructed when individuals engage socially in talk and activity about shared problems or tasks" (Driver et al., 1994, p. 7). Thus, social discourse is viewed as a crucial element in student's learning. Driver, Newton and Osborne (2000) argued that conceptual change demands more than physical experiences that induce conflict, and is "dependent on the opportunity to socially construct, and reconstruct, one's own personal knowledge through a process of dialogic argument" (p. 298). Group discussions are seen as being crucial to student learning (Driver et al., 1994; Driver, Newton, & Osborne,

2000; Tobin, Tippins, & Gallard, 1994), as students are exposed to alternative conceptions which can lead to negotiation of these conflicting ideas to reach consensus.

Bell (2005) argued that discussions in class can provide opportunities for students to compare their ideas to those of others, test their understandings, ask questions and challenge the views of others students and the teacher. Through this process, the students will be challenged to reconstruct their understandings toward a more scientifically accurate conception. He asserted that discussion in small groups has been shown to promote conceptual development in the Learning in Science Projects and that, "it was not the activity *per se* that promoted learning, but the language and thinking involved in completing the activity" (p. 174).

However, the process of involving students in such negotiations is seen to be a critical role of the teacher. For as Driver et al. (1994) argued, "if students are to adopt scientific ways of knowing, then intervention and negotiation with an authority, usually the teacher, is essential" (p. 11).

Current reform efforts and inquiry

The major science education reform documents developed in the 1990s continue to stress the importance of inquiry in education and reflect the arguments that have been made before by Dewey, Schwab, those who promoted constructivist learning theories and many others. *Science for All Americans* (American Association for the Advancement of Science, 1990) asserted that the teaching of science should be consistent with scientific inquiry and the *National Science Education Standards* (referred hereafter as the *NSES*) (National Research Council, 1996), emphasized that "inquiry into authentic questions generated from student experience is the central strategy for teaching science" (p. 31).

What is inquiry?

Researchers have defined inquiry in many different ways resulting in the lack of a clear definition in the literature (Anderson, 2002). In the *NSES* (National Research Council, 1996), inquiry is viewed as both the way in which scientists develop new knowledge and as a way for students to learn. Scientific inquiry is defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work", and "the activities through which students develop knowledge and understanding of scientific ideas, as well as understanding of how scientists study the natural world" (National Research Council, 1996, p. 23). The varying perspectives on inquiry are reflected in Minstrell's comment that "we may agree more easily on what inquiry isn't than on what it is" (Minstrell, 2000, p. 472).

Asserting that students should both learn to do science and develop an understanding of what science is, in the *NSES* (National Research Council, 1996) it was proposed that students should develop both the "abilities necessary to do scientific inquiry", including identifying and posing questions, designing and conducting investigations, analyzing data and evidence, using models and explanations and communicating findings and "understandings of scientific inquiry", including a knowledge of how scientists conduct their work and concepts related to the nature of science (National Research Council, 1996, p. 121).

In addition to being a topic that students should understand and skills that they should develop, inquiry has been promoted as a teaching method to help students learn scientific concepts (Colburn, 2000; Flick, 1995; National Research Council, 1996). Reflecting the arguments put forth over the past one hundred years for the use of inquiry in the classroom and more recent understandings of how students learn, the authors of the *NSES* claimed that:

> Inquiry is central to learning science. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills (National Research Council, 1996, p. 2).

While there are many different understandings of what inquiry is, five essential elements of classroom inquiry have been suggested (National Research Council, 2000, p. 25). These are:

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

The degree to which the students are engaged in these essential features, and the role that the teacher plays, varies depending on the particular goal and concept to be learned during a particular set of lessons (National Research Council, 1996). For example, Colburn (2000) stated that inquiry ranges from structured forms where the teacher provides the questions to investigate, procedures and materials, but generally has students determine what data to collect and develop an explanation for observations, to guided forms where the teacher typically provides only the question and materials to open forms where the students are responsible for all elements of the inquiry. This is in contrast to what is often called a "cookbook" or traditional hands-on activity, where the students are even told which data to

collect and are simply attempting to verify what has already been learned in the classroom, a process that Bonnstetter (1998) argued "simply is not inquiry science" (p. 3).

Yet, while inquiry is seen as central in helping students understand science, the authors of the *NSES* (National Research Council, 1996) emphasized that inquiry is not the only method to be used in science instruction. Reflecting this belief that inquiry plays a crucial role in science education, but is not the sole instructional strategy to use, many authors have referred to current best practices in science education as "inquiry-oriented teaching" (Flick, 1995), "inquiry-based instruction" (Keys & Bryan, 2001), reform pedagogy (Anderson, 1996) and similar phrases to acknowledge the crucial role of inquiry within an overall constructivist-based pedagogy.

Affects on student outcomes

Many claims have been made as to the effect of inquiry-based instruction on student outcomes, including statistically enhanced performance in achievement, process skills, problem solving, and attitude toward science (Haury, 1993; Shymansky et al., 1990). However, skepticism and caution have been urged when considering these claims (Kirschner, Sweller, & Clark, 2006). For example, DeBoer (1991) in reviewing research studies on the effectiveness of inquiry and non-inquiry strategies conducted during the 1960s and 1970s, concluded that they were generally inconclusive.

While acknowledging that "caution must be used … in interpreting reported findings" (p. 3), Haury (1993) asserted that studies of inquiry-oriented teaching and the inquiry-based programs of the 1960s "have generally been supportive of inquiry approaches" (p. 3). Shymanksy et al. (1990), in a reanalysis of research dealing with student performance after use of inquiry methods, acknowledged that the new analysis suggested that inquiry was not

as effective as previously thought, yet still concluded that "The new science curricula of the sixties and seventies were more effective than the traditional textbook programs of the time" (p. 143). Others have argued that the results of research on inquiry-oriented instruction have been mixed with "the clearest effects occurring with more capable students, who have well trained teachers, and a supportive classroom atmosphere" (Flick, 1995, p. 17). More recently, Anderson (2002) in reviewing several meta-analysis that occurred in the 1980s on inquiry teaching, as well as reviews from the 1990s, concluded that "a pattern of general, but not unequivocal, support for inquiry teaching continues to come from the research" (p. 6).

Regardless of whether or not there is sufficient research evidence to support the claims that inquiry-oriented instructional practices lead to numerous improvements in students, as reported previously, science education reform is currently centered on inquiry. Anderson (2002), in discussing research on the effectiveness of inquiry, argued that "as research in this area has matured, it has tended to move away from the question of whether or not inquiry teaching is effective, and has become focused more on understanding the dynamics of such teaching and how it can be brought about" (p. 6).

In summary, based on century long claims that students' understanding of science can be improved when they use investigative methods similar to those scientists' use, and supported by research findings suggesting this improved learning can occur, inquiry is once again the focus of efforts to reform science education. The crucial role of the teacher in implementing inquiry is examined next.

Teachers' roles in implementing inquiry

Anderson (1996) argued that science teaching can be viewed as a continuum from traditional to reform pedagogy. In traditional pedagogy, the role of the teacher can be

described as a dispenser of knowledge with the student a passive receiver of knowledge and the activities teacher-prescribed. In contrast, in the reform pedagogy, the teacher's role is that of coach and facilitator, with the student a self-directed learner and the activities being chosen and developed by the student.

While some may view instruction where the student has more control as requiring less effort on the part of the teacher, Flick and Dickinson (1997)argued that "initiating, conducting and maintaining a sense of inquiry as a part of instruction in science is a highly complex form of teaching" (p. 1). Crawford (2000) argued that while many see the amount of teacher involvement as being least in a discovery learning setting and most for the traditional format, with inquiry falling in between, inquiry-based teaching actually requires the most teacher involvement as the teacher has many roles to take; including mentoring students in developing data collection plans, modeling the systematic analysis of data and monitoring the students' reports explaining the projects. Clough (2002) wrote that:

> The end result [of effective inquiry learning experiences] appears to a layperson as simply hands-on learning, but to the expert teacher sensitive to the intricacies of learning, it is far more complex than that. Both the student and teacher are thinking, but at different planes. The most significant difference is that while students are connecting these hands-on experiences to their current and emerging conceptual framework, the teacher is desperately trying to understand students thinking to further engage them in that construction of knowledge. Hence, placing greater responsibility on students does not mean simply having them figure things out on their own. Rather than abdicating responsibility for teaching, an understanding of how people learn demands from teachers a far more complex and demanding role in promoting students understanding of science. (p. 93)

The authors of the *NSES* (National Research Council, 1996) also acknowledged that there is a continuum of science teaching practices and emphasized the crucial role that teachers play in implementing inquiry-oriented science instruction, listing nine changes that teachers

should make in their practice in order to effectively implement inquiry-based instruction. These changes are summarized as contrasts between the "less emphasis" conditions that are commonly observed in classrooms to the "more emphasis" conditions that are indicative of inquiry-oriented teaching and learning. The changes to the teaching standards as suggested include (National Research Council, 1996, p. 52)

LESS EMPHASIS ON	MORE EMPHASIS ON
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interest, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students

However, while the suggested changes paint a general picture of what a teacher should do in the classroom, many educators (Anderson, 2002; Clough, 2002; Keys & Bryan, 2001; Lunetta, Hofstein, & Clough, 2007) asserted that the standards do not provide clear guidelines as to what actions a teacher should take. While this does provide flexibility for those teachers who understand how to implement inquiry to "create modes of inquiry that fit their local classroom situations" (Keys & Bryan, 2001, p. 632), teachers who lack an

understanding of inquiry-based pedagogy are "left to create his or her own images of what constitutes this form of teaching" (Anderson, 2002, p. 3).

Part of the difficulty in providing a clear picture of what teachers should do to implement inquiry-based instruction is that research has yet to provide definitive answers. Flick (1995) argued that there has been a "persistent lack of data about the nature of teacher behavior in inquiry-oriented teaching" (p. 3) and noted that "much of the current work on inquiry teaching has focused more on student learning and less on how teachers structure the environment and interact with students to bring about maximum opportunities for that learning" (p. 17). In addition, researchers argued that there is still much to be learned about what counts as effective inquiry instruction, including teacher practices and the use of inquiry in culturally diverse classrooms, (Flick, 2000; Fradd & Lee, 1999; Keys & Bryan, 2001; Songer, Lee, & McDonald, 2003).

However, much has been learned about effective instruction in general, and in specific regarding inquiry-oriented practices, that can provide a general basis for what constitutes instructional best practices at this time. In the following section, research on effective teaching and the use of inquiry-oriented teaching practices will be reviewed.

Effective teaching practices

Two methods for determining what constitutes effective teaching practices have dominated research in this area. One method involves comparing exemplary and non-exemplary teachers and looking for differences that can account for the variance in ratings. The other method involves changing specific teacher practices and examining student outcomes for any positive impact that may have occurred due to changes in the teacher's practice, also referred to as behavior, a line of research often called process-product. Both

methods have been conducted in a variety of class settings, with differing subject matter and grade levels of students. Many reviews have been written regarding what are considered the best practices derived from this line of research (Brophy & Good, 1986; Kumar, 1993; Tobin et al., 1994).

However, these two approaches have been used in a variety of conditions, many of which may not have been congruent with those needed for effective use of inquiry in the classroom. For example, the results from a study conducted where the learning goal was mastery of multiplication tables, a goal suitable to drill and practice methods, may be of little benefit for understanding what constitutes effective inquiry practice. Thus, to gain a better idea about specific pedagogic practices that are needed to implement inquiry effectively, researchers began to examine teachers as they implemented inquiry-based instruction in an effort to determine the actions that are taken to create the conditions in which students are more likely to learn using inquiry (Crawford, 2000; Keys & Bryan, 2001; Omar, 2004).

Kumar (1993) , in a review of the literature on effective instructional practices, developed nine categories of instructional behaviors related to the cognitive, affective and societal aspects of science education. He concluded that effective teachers:

- Use scientifically correct content in their explanations and representations and examples.
- Organize and sequence instruction in small increments and at appropriate difficulty levels.
- Provide concrete experiences to assist students in constructing a meaningful understanding of scientific concepts.
- Use questioning strategies that enhance conceptual understanding, for example, asking students to explain concepts in their own words and probing their responses to reveal misunderstandings in their understanding.

- Use questioning strategies that develop critical thinking and problem solving skills such as by asking questions requiring comprehension, application or analysis of ideas.
- Provide cues and redirect student questions to enable them to arrive at their own answers.
- Provide adequate wait time for students to respond to questions.
- Create a classroom environment that develops better student attitudes toward science, for example, by treating all students with respect and not embarrassing them when mistakes are made.
- Use interesting and challenging science activities and relate concepts studies in class to contemporary societal issues which can improve student achievement and attitudes toward science.

Management

In addition to these teaching practices, others have argued that effective management of the classroom is also an important trait of effective teaching. While the dominant mode of instruction observed in most classrooms is one that emphasizes order and control (Gallagher & Tobin, 1987), and thus is highly managed and does not resemble the conditions one would expect for inquiry to occur, studies of exemplary science teachers have found that they also demonstrated significant managerial skill while still promoting inquiry (Tobin & Fraser, 1990). Treagust (1991), in a study of two exemplary teachers who had different practices yet engaged students in developing an understanding of science concepts, reported that both teachers utilized a high level of managerial efficiency, including smooth transitions from one activity to another, which provides little opportunity for off-task behavior by students. As Flick (1995) has suggested, “It might be inferred … that highly skilled teachers manage both kinds of instruction, teacher control and active inquiry, very likely at the same time” (p. 2).

Questioning

While there are many different teacher practices that have been identified as important, those practices that relate to the use of questioning are argued by many to be the most crucial, as noted by five of the nine categories Kumar developed relating to questioning. Numerous articles have been written to assist teachers in developing effective questioning skills (Blosser, 1991; Martens, 1999; Penick, Crow, & Bonnstetter, 1996; Vogler, 2005; Wilen, 2001). Tobin, Tippins and Gallard (1994), in reviewing the data on exemplary teachers, argued that "The key to teaching with understanding was verbal interaction that enabled teachers to monitor students' understanding of science concepts" (p. 53). In discussing the importance of questioning in developing student understanding, Penick et al. (1996) asserted that:

> Questioning a student and listening closely to the response allows us to assess what students think and why they have that particular idea. When, as teachers, we know what they think, we can proceed to place the student in situations where the concept can be demonstrated, talked about, questioned, tested, or otherwise explored. The student is more likely to develop ideas congruent with scientific thinking, for, as was noted years ago, language precedes logic. (p. 29)

There are a variety of purposes for which a teacher may ask a question, including to: help students review, check on comprehension, stimulate critical thinking, encourage creativity, emphasize a point, control classroom activities and reduce disruptive behavior, help determine grades, and encourage discussion (Blosser 1991). Perhaps the most important purpose for asking questions is that the teacher can help students to reason through problems rather than telling them the answer as Clark et al., (2000) asserted that "with well-phrased questions, the teacher can guide students to see discrepancies in their thinking and consider alternatives without telling them exactly what to do" (p. 42).

Many systems have been developed to categorize the types of questions that teachers ask; perhaps the most well known is Bloom's Taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). In Bloom's system, questions are categorized based on the perceived level of cognitive processing required by the student to provide an answer. The lowest levels of questions are considered to relate to a student's knowledge and ask only for the recall of information. Subsequent levels of questions are comprehension, application, analysis, synthesis, and the highest level is evaluation where students are asked to form a judgment regarding a specific idea or concept. To assist students in developing better understanding of the concepts studied, teachers are urged to utilize a larger percentage of the higher level questions than those that simply require recall of information.

This is not to say that there are not times when lower level questions should not be used. In addition to thinking about the cognitive level of the questions that are being asked, teachers also need to understand question sequencing (Vogler, 2005), that is, designing a series of questions such that each new question builds on the previous. Research has shown less than five percent of questions are structured as part of a sequence of more than four questions (Wragg & Brown, 2001 as cited in Vogler, 2005). The HRASE strategy (Penick et al., 1996) categorizes questions as relating to history, relationships, application, speculation and explanation and allows for a teacher to ask questions requiring less cognitive processing first, such as "What has occurred in your experiment so far?" proceeding to more difficult questions asking the students to explain how their data can be accounted for; strategies such as this help to create the safe intellectual environment required for effective questioning to occur (Olson & Clough, 2004). Perhaps the most critical point in developing a sequence of questions and determining the types of questions to use is to remember that "recall of

information should never be the end product or goal, however, it should be the means to the end of achieving critical of reflective thought about a … problem" (Wilen, 2001, p. 28).

Research into teachers' questioning skills has indicated that the majority do not use questioning effectively (Downing & Gifford, 1996; Gall, 1984; Wilen, 1987). For example, questions emphasizing recall of facts and information typically dominate lessons, with estimates of use from 60% to 85% of all teacher questions. Others have reported that questions that require students to formulate generalizations and give original or novel responses account for only five percent of the questions asked (Cunningham, 1987). In addition, Hoetker and Ahlbrand (1969) reported that teachers in junior high English classes asked as many as five questions a minute. Thus, teachers typically ask many questions, few of which challenge students cognitively.

These studies illustrate the pattern most often used in asking questions - the recitation. Researchers throughout this century (Gall & Rhody, 1987) have documented teachers' reliance on recitation. Recitation is characterized by the teacher asking frequent questions, often in rapid-fire fashion, to test students' mastery of content. Teachers' control what questions are asked, choose who gets to answer, and give responses to the answers. The student only answers questions when called on by the teacher and listens to other teacher-student interchanges. Others have described this sequence, where the teacher asks a question, the student replies and the teacher praises or corrects the response as Initiation-Response-Evaluation (IRE) (Alvermann & Hayes, 1989; Alvermann, O'Brien, & Dillon, 1990) and the Triadic dialogue (Lemke, 1990).

While choosing the appropriate categories of questions to ask and developing extended sequences is a crucial component of effective questioning, others factors have also been

found to play important roles in a teacher's questioning practice. These include wait time, teachers' responses to student answers and non-verbal behaviors that teachers' use during questioning (Clark et al., 2000).

Wait time

Rowe (1974, 1986) defined the time that a teacher waits after asking a question for a student to respond as 'wait time I' and the time the teacher waits after the student gives an answer before responding as 'wait time II'. Studies have demonstrated that teachers typically wait less than one second for a response after asking a question before they will repeat, rephrase, ask a different question or call on another student, and that teachers typically wait less than one second after a student response before calling on another student or asking another question (Rowe, 1974; Tobin, 1980).

As to the effect of extending wait time, experimentation has shown that three to five seconds is optimal for wait times I and II (Rowe, 1974; Rowe, 1986; Tobin, 1980; Tobin, 1986). In studies where wait time was manipulated, the increased wait time accounted for 18 to 25 percent of the variance in students' science achievement test scores (Baker & Piburn, 1997). Rowe (1974) identified many of positive effects of increased wait time on both students and teachers, including:

Student

- The length of student responses increases between 300 and 700 percent.
- Inferences are more likely to be supported by the use of evidence.
- The incidence of speculative thinking and student-generated questions increases.
- Failures to respond to questions decrease and classroom discipline improves.
- Students ask more questions.

- The variety of students who participate voluntarily increases.
- Student to student exchanges increase.
- Student achievement on cognitively complex test items improves.

Teacher

- Teachers exhibit greater flexibility in their responses to student.
- The number of questions asked decreases, while the number of higher-cognitive level questions asked increases.
- Expectations for student performance improves.

Response

The way in which teachers respond to a student answer is also important to using questioning effectively. Shymansky and Penick (1981) argued that teachers reducing certain restrictive classroom behaviors, including highly evaluative feedback in the form of praising students for correct responses and behavior while rejecting students for incorrect responses and behaviors, will result in "task-oriented, more successful students who are more likely to be self-motivated and ready and willing to learn in science" (p. 421). Rather than judging students answers as either being correct or incorrect, teachers could acknowledge students comments by writing the ideas on the board, using the ideas as a way to move onto other ideas, or ask the students to elaborate of their response (Olson & Clough, 2004).

A teacher's response to a student's answer can also help to promote discussion among the students and avoid students only listening to the teacher (Blosser, 1991). For example, student interaction can be encouraged by the teacher using remarks such as "What do you think about Fred's idea?". Through this extended discussion of the ideas, students will often

recognize errors in their thinking that can lead to changes in their ideas, without the teacher making an explicit evaluation of their ideas (Olson & Clough, 2004).

In addition to the effect of the type of questions asked and the responses given in creating a safe classroom environment, teachers are also encouraged to exhibit positive non-verbal behaviors, described as "actions that demonstrate interest and withhold judgment" (Clark et al., 2000, p. 40). These gestures include smiling (Wubbels & Brekelmans, 1998), eye-contact, movement around the room, leaning forward when students are speaking, raising eye-brows to show interest, and inviting hand gestures.

Limitations of using effective teaching research for implementing inquiry

While research on effective teaching would seem to provide a detailed pedagogical prescription for teachers, many have argued that several limitations of the process-product and effective teacher research may reduce the extent to which the results are applicable in inquiry-based instruction. Yager et al. (1988) asserted that while teacher behavior has been studied extensively for some time, success was usually determined by student achievement on instruments that often emphasized knowledge and simple skills; rather than the deeper conceptual understanding advocated by reformers. Others have asserted that the evidence supporting the conclusions that certain teacher behaviors maximize student achievement are strongest for basic skills instruction in the primary grades and that "process-product relationships do not translate directly into prescriptions for teaching practice" (Brophy & Good, 1986, p. 365).

Richardson and Placier (2001) argued that there has been a widespread realization that "while teachers could be trained in behavior, training them to make decisions about the appropriateness of a particular behavior within a specific context was much more difficult"

(p. 914). Rather than viewing the conclusions drawn from research on effective teaching as providing a prescription for teacher behavior, many have argued that the research results provide important information that teachers should utilize in their decision making processes rather than rules to be followed mechanistically (Brophy & Good, 1986; Olson & Clough, 2004; Tobin et al., 1994).

Many have also argued that what constitutes effective instruction and the role the teacher plays varies with context such as the particular composition of a class, the subject matter being taught or specific instructional objectives being pursued (Brophy & Good, 1986; Tobin et al., 1994), and thus the teacher behavior required changes along with context. Flick (2000) argued that during observation, "instruction may look less student-centered and therefore less in alignment with commonly accepted views of standards-based teaching practice" (p. 111) when a teacher is adjusting or redirecting instruction in order to reengage students in the inquiry. For example, a teacher may need to ask a series of lower-level questions in order to assist students in recalling information that will allow them to construct new understanding.

Several research studies have supported the assertion that there is no one way in which inquiry should be implemented in regards to teacher actions. Garnett and Tobin (1988) found that two teachers whose practice was seen as exemplary in their study both focused on teaching for understanding; yet one teacher tended to emphasize whole-class activities while the other used more small-group and individual activities. While one teacher carefully presented and explained new material, the other carefully planned experiences to assist the students in structuring their own learning. However, in both cases, the lessons were carefully sequenced and linked and concrete models were used to facilitate understanding.

Songer et al. (2003) reported that in a study of teachers in urban areas with large class sizes, no teacher aides and students with little previous inquiry experience, the teachers used whole class instruction more than small group instruction which is the often described as preferred practice for inquiry learning. They suggested that such an approach might be required until the students gain enough experience to assume more responsibility for developing investigations.

Thus, it would seem that determining what effective inquiry-based instruction involves is not a simple task. As Duschl and Gitomer (1997) argued, "research has made it clear that expertise in teaching is more that just management of activity; it involves effective execution of complex cognitive tasks" (p. 39), including "not only the management of actions, materials and behaviors, but also…the management of reasoning, ideas and communication." Perhaps then as one examines teaching to determine if effective practices are occurring, the learning that is occurring must be the key indicator as argued by Songer et al. (2003) "in thinking about what science inquiry looks like in diverse school settings, the quality of the intellectual engagement among students should hold more sway than making sure classroom methods match with a pre-established vision of best practice" (p. 514).

Teachers' implementation of inquiry-based instruction

While the research literature does not yet provide conclusive evidence regarding the effects of inquiry-based instruction on student outcomes, research on the implementation of inquiry in the classroom has shown repeatedly that inquiry-based instruction does not occur to the extent or as effectively as desired. Numerous studies that examined the use of inquiry-based curricula developed in the 1960s and 1970s suggested that the effective use of inquiry in the typical science classroom was not as widespread as hoped (Harms & Kahl, 1980;

Harms & Yager, 1981; Weiss, 1978). Stake and Easley (1978) found that while many teachers were using the inquiry-based curriculum materials designed to foster inquiry teaching, these were not being used in the manner intended. Rather, in observations of science classrooms across the country, researchers found that the majority of teachers were using traditional didactic methods such as lecture (Harms & Yager, 1981), and that overall the instruction in classrooms was one that emphasized order, control and material to be covered (Gallagher & Tobin, 1987).

Despite twenty years of efforts to improve the use of inquiry in the classroom, very little has changed (Crawford, 2007). Pasley et. al. (2004), based on 180 classroom observations of science lessons using a structured protocol, reported that fifty-nine percent of the lessons were judged to be low in quality and "unlikely to enhance students' understanding of important mathematics/science content or the ability to engage successfully in the processes of science of mathematics" (p. 2). In contrast to the high percentage of low quality lessons, only fifteen percent of the lessons observed were judged to be of high quality that would likely enhance students understanding of important concepts and develop their ability to do mathematics/science successfully. In addition, the laboratory is still not used in a manner consistent with Schwab's call for inquiry in the classroom. For example, a recent U.S. Department of Education report noted that 69% of 12th graders surveyed indicated that they had "never" or "hardly ever" designed and carried out their own investigation (U.S. Department of Education, 1999). Based on the numerous studies documenting how ineffectively inquiry-based instruction has been used in the classroom, Bybee (2000) concluded that "most evidence indicates that science teaching is not now, and never has been, in any significant way, centered in inquiry whether as to content or as technique" (p. 42).

Teacher difficulties implementing inquiry

Studies of the use of inquiry-based curricula revealed that teachers experienced many difficulties in attempting to implement inquiry in the classroom. Welch et al. (1981) noted that:

> The widespread espoused support of inquiry is more simulated than real in practice. The greatest set of barriers to the teacher support of inquiry seems to be its perceived difficulty. There is legitimate confusion over the meaning of inquiry in the classroom. There is concern over discipline. There is worry about adequately preparing children for the next level of education. There are problems associated with the teachers' allegiance to teaching facts and to following the role models of the college professors. (p. 40)

Anderson (2002) claimed that there are both external barriers and internal dilemmas that a teacher must overcome in order to successfully implement inquiry teaching. Based on a cross-site analysis of case studies of schools that had successfully initiated new approaches to science instruction, Anderson (1996) proposed that these barriers and dilemmas were clustered into three dimensions, technical, political and cultural.

The technical dimension referred to teachers having the required content knowledge, teaching knowledge, such as how to effectively design assessment, and skills including questioning, to effectively implement reform pedagogy. For example, Anderson (1996) reported that while some teachers were committed to teaching for understanding, they did not have a full understanding of the teaching practices required to accomplish this and were not successful in utilizing the new approaches. Other barriers in this dimension included managing classroom tasks such as group work, the challenges of new teacher and student roles, inadequate inservice education and having the time to plan, implement instruction and collaborate with other teachers.

The political dimension referred to barriers created by political issues and included factors such as lack of school or district level leadership, parental resistance to change, lack of public support, and inadequate resources. For example, school wide collaboration may be limited due to political barriers when other departments do not wish to engage in reforming educational practices. In addition, ensuring that district curriculum guidelines are met while implementing inquiry often creates a barrier for teachers attempting to implement inquiry (Duschl & Gitomer, 1997; Keys & Kennedy, 1999). For example, Yerrick et al. (1997) reported that district demands that student performance on statewide-mandated end-of-grade science tests not decline negatively affected the way in which the teachers implemented the suggested inquiry-based practices in the classroom.

While Anderson (1996) asserted that an "appropriate set of actions" (p. 67) in the political dimension can be crucial to implementing reform pedagogy, he argued that the cultural dimension, the beliefs, perceptions and values held by teachers about teaching and learning, is the most crucial to the success of reform efforts. Anderson argued that this is the most important set of barriers and dilemmas to address as research indicates that teacher' beliefs are a key factor in whether or not instructional practices are changed. For example, teachers in the case studies often had prior commitments, such as the belief that students learn best from the textbook, which prevented them from implementing reform pedagogy. Anderson also argued that the "preparation ethic" belief, in which teachers are committed to coverage of large amounts of material to prepare students for the next level of schooling, must be changed. Other cultural barriers that have been reported include moving beyond viewing physical involvement in group work as collaboration rather than the exchange of

ideas (Marx et al., 1994), and using assessment to plan instruction rather than as only a summative measure (Duschl & Gitomer, 1997).

Many researchers have argued that many of the technical and cultural barriers that teachers experience may be due to their prior educational experiences. For example, Alberts (2000) asserted that many teachers have difficulty using inquiry oriented instruction as they have never participated in scientific inquiry themselves due to the way that science is taught in college. Davis (2003), argued that what students have come to understand and believe about teaching and learning is not congruent with reform practices, asserting that,

> Thus, new and experienced teachers, as a result of their experiences as students in traditional classroom settings, hold beliefs and understandings about the nature of science, the disciplines, and how they are best taught and learned that are counter to the principles underlying the new instructional approaches they are being asked to put into practice. (p. 6)

In summary, while there is no specific set of pedagogical practices that will enable all teachers to effectively implement inquiry in their classrooms, decades of research on effective teaching and the use of inquiry has provided a picture of the variety of actions that teachers might take. However, numerous barriers have been identified that inhibit teachers from effectively utilizing inquiry in the classroom, including a lack of understanding of the pedagogical practices required, and beliefs about teaching and learning that are not congruent with the underlying premises of inquiry-based instruction. The crucial role that the teacher has in implementing inquiry has led to efforts to assist teachers in changing their practice that will be discussed in the next section.

Teacher Change

Need for teacher change

Curriculum reform has been claimed as central to implementing inquiry-based instruction in the classroom (Bybee & Ben-Zvi, 1998). Many educators have argued that curriculum developers often neglected to attend to key aspects of implementation, including allotting adequate time, developing strategies to assist teachers in making needed changes, and providing adequate staff development opportunities, such that teachers could effectively implement the new curricula (Loucks & Pratt, 1979; Patterson & Czajkowski, 1979; Richardson & Placier, 2001). For example, based upon analysis of research studies conducted on inquiry-based curricula of the 1960s and 1970s, it was found that student performance was only statistically enhanced if teachers had attended inservice sessions designed to support the implementation of the new curricula (Shymansky et al., 1990). Results such as this led some to conclude that "after many years of curriculum revision, it is probably safe to say that classroom instruction in science is not a teacher proof phenomenon – how the teacher uses instructional materials does make a difference" (Shymansky & Penick, 1981, p. 412).

Scholars have argued that significant change is required in teachers' pedagogical knowledge and views about teaching and learning, including their orientation towards classroom organization, activities and student interaction, in addition to their content knowledge (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Richardson & Placier, 2001;). Reflecting the mounting arguments and evidence for changes in teachers' practice as the most influential factor in educational change (Anderson & Helms, 2001; Ball & Cohen, 1996; Beck, Czerniak, & Lumpe, 2000; Bransford, 2000; Fullan, 2001; McLaughlin &

Talbert, 1993; Peers, Diezmann, & Watters, 2003; Schneider & Krajcik, 2002; Tobin et al., 1994). Yager and Lutz (1994) argued that "to improve student learning, it will be necessary to focus on a change in teaching. Teaching strategies must be congruent with learning processes: This cannot be said too often" (p. 344).

Despite research strongly suggesting that effective professional development must accompany implementation of new curricula, this still does not always occur today. Kelly and Staver (2005), in a study of a school system that adopted and implemented a new K-6 kit-based science curriculum in which there was no professional development included, concluded that "traditional science teaching remained the norm" (p. 25). The authors suggested that "a systematic, ongoing program of professional development is necessary to address teachers' concerns and help the district realize its goal of standards-based K-6 instruction" (p. 25), including planning, preparing for, teaching, and using inquiry-based instruction.

Teacher change

Teacher change has been referred to in the literature by many labels, including learning, development, socialization, growth, improvement, implementation of something new or different, cognitive and affective change and self-study (Richardson & Placier, 2001). Regardless of the term used, teacher change efforts are typically based on the assumption that improving the pedagogical practices, beliefs and attitudes of teachers will produce higher levels of student achievement (Guskey, 1986; Guskey, 2002; Richardson & Placier, 2001; Supovitz & Turner, 2000). For example, Davis (2003) defined teacher learning as the "process of acquiring new ideas, changing or deleting old ones, and gleaning new knowledge and skills" (p. 5).

Teachers can learn, and thus change, in many different situations, including from their own practice, through interactions with other teachers, from teacher enhancement programs, and through graduate study (Bransford, 2000). While the impetus for change is often external (Arora, Kean, & Anthony, 2000), Richardson et al. (1991) argued that teachers constantly make voluntary changes to their practice, keeping those that seem to work for their students, which can result in major and dramatic improvement in their teaching.

However, others have contended that the changes teachers make are typically minor and inconsequential (Cuban, 1988). Acknowledging that the decisions teachers' make as to whether an activity works may be unconscious and uninformed, resulting in the teacher misjudging the effectiveness of a particular activity; Richardson (1998) asserted that "while voluntary change is what teachers actually do in their classrooms, it does not necessarily lead to exemplary teaching" (p. 2) and suggests that teachers do need assistance in making changes that are congruent with currently recommended reforms. In the end, however, whether a change is voluntarily undertaken or mandated, scholars have acknowledged that teachers will ultimately determine to what extent and in what way the change is implemented (Beck et al., 2000; Richardson & Placier, 2001).

Historical approach to change

While teacher change efforts have been emphasized in reform efforts for decades, most agree that, in general, these efforts have not resulted in long-term change to teachers' practice (Guskey, 1986; Guskey, 2002; Loucks-Horsley et al., 2003; Richardson & Placier, 2001). For example, in a four year study of teachers who had undergone a professional development program based on Madeline Hunter's work with structured instruction, it was found that in the third year teachers implemented the desired behaviors much less often than during in the

first two years (Porter, 1986; Stallings & Krasavage, 1986). While there were short-term positive changes in teachers' pedagogical practices, the improvement was reversed once the support from the professional development personnel was stopped, suggesting that no long-term change had occurred.

Teacher change efforts of the past were often carried out in the form of a training model based on the assumption that the effective behaviors and techniques identified through research should be replicated by teachers and that teachers could learn or change their behavior to replicate these practices (Richardson & Placier, 2001). The changes that teachers were asked to implement were often based on research conclusions and/or theory that conflicted with their understandings and beliefs about effective instruction and how students learn. In addition, these traditional change efforts were typically short in duration (Loucks-Horsley et al., 2003). Thus teachers did not have time to construct understanding with others, and to reflect on the results of new practices and make further refinements; conditions that many have argued, do not reflect what is known about how people learn (Bransford, 2000; Marx, Blumenfeld, Krajcik, & Soloway, 1997).

In summarizing the prevalent view among those involved in teacher change efforts, Marx (1997) argued that traditional practices would not be successful, stating "the literature on teacher change is clear – change will not take root and innovation will not be sustained if one adopts traditional top-down models of dissemination that rely on single workshops, distribution of curriculum materials to be used exactly as prepared, and lists of prescribed practices" (p. 349). Echoing these thoughts on change efforts, and what will be required of teachers, Anderson and Mitchner (1994) argued that:

> It is evident that changing the actions of teachers, especially toward using more inquiry-oriented teaching approaches, is definitely more complex than originally thought. Change does not occur by simply altering such variables as how teachers feel and act. Rather, these desired changes require teachers to learn, rethink, and adopt different knowledge, thoughts, and practices related to teaching. (p. 28)

Current thoughts on teacher change

While the majority of teacher change efforts have not produced long-term change, the results of some small scale projects and more recent large scale programs provide research based evidence for how efforts to change teachers practice may be improved (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Weiss & Pasley, 2006). For example, Marx et al. (1997) described four key elements involved in efforts to assist teachers in successfully implementing a project-based science curriculum that attempted to deal with many of the previously mentioned shortcomings of traditional change efforts. These key elements were: collaboration with others, enactment of new practices in classrooms, extended effort (time) to initiate changes, and reflection on practice. Based on four case studies, Marx found that teachers benefited from the professional development program based on these four key elements and, while a range of practices was exhibited, made improvements and were able to use the project-based curricula successfully.

In the *NSES* (National Research Council, 1996) a view of how teacher improvements efforts should change was presented. For example, there should be less emphasis on “courses and workshops”, and more emphasis on “a variety of professional development activities” (p. 72).

In addition, many lists of the elements of effective teacher change efforts have been suggested (Davis, 2003; Gess-Newsome, 2001; Loucks-Horsley et al., 2003). The following

list, based on a review of the literature on effective teacher change efforts, summarizes the elements that appear to be key in the development of new understandings and practice that reform efforts must address (Davis, 2003, p. 7):

- Enable teachers to reflect upon and make explicit their personal practical knowledge, including beliefs, attitudes, and concerns,
- Consider teachers' knowledge and practices as the starting point of change,
- Provide teachers with experience and training in reform-based strategies,
- Provide teachers opportunities to see these approaches modeled and to reflect upon these models,
- Enable teachers to design inquiry-based instruction and practice these approaches in the context of supportive classroom environments where feedback is provided,
- Provide teachers with collaborative settings with other educators,
- Provide teachers access to experienced professionals as mentors and guides.

Time

The list of key elements for effective teacher change efforts suggests that this is a very complex process. However, the research literature suggests that one aspect plays a critical role in teacher change – the amount of time spent in the efforts. Loucks and Pratt (1979) noted many years ago that "change is a process, not an event" in arguing that change takes time, a view supported by many other scholars (Blumenfeld et al., 1994; Davis, 2003; Gess-Newsome, 2001; Luft & Pizzini, 1998; Marx et al., 1997). Researchers who have worked closely with teachers in implementing educational innovations have reported that it takes from eighteen months to three years for teachers to fully grasp the ideas underlying the new innovations and acquire mastery of the practices required (Blumenfeld et al., 1994; Huberman & Miles, 1984).

Teachers' apparent need for extensive amounts of time in order to change may be due in part to the way in which this change occurs. The change process has been described as slow, idiosyncratic and fragmented. For example, teachers during the first year of a professional development program were found to be focused on changes in their practice rather than understanding the premises underlying Problem-Based Instruction (Blumenfeld et al., 1994). Arora et al. (2000) described how a teacher was able to incorporate many elements of inquiry into her practice; however rather than making revolutionary changes, she incrementally implemented ideas that were important to her. In addition, not all parts of her practice changed equally; while the teacher made considerable change in the curriculum and learning activities used, and in her beliefs about students' abilities to do inquiry, very little change was made in the areas of classroom control and assessment.

Others have described change as a process that might best be described by the old adage "two steps forward and one step backwards". For example, Marx et al. (1997), argued that "overall, teachers' progress is not linear; they move between old and new ideas and practices" and noted that "teachers advance and retreat as they confront dilemmas and attempt to meet challenges posed by the new approaches to teaching for understanding" (p. 349).

Further support for the critical role that time plays in promoting teacher change comes from studies of large scale professional development efforts. Several studies of the impact of the Local Systemic Change (LSC) professional development program have documented the effect that increasing amounts of professional development have on teachers' practice. Weiss et al. (2004) reported that teachers who had received at least 20 hours of LSC professional development were more likely to receive high ratings of their lessons. Upon further study, it

was found that impacts of teachers' use of inquiry-based instruction were detectable after thirty hours of professional development, with the effect increasing through eighty hours (Weiss & Pasley, 2006). Teachers who had at least 80 hours of professional development and used the supplied curriculum materials were found to be twice as likely to receive a high evaluator rating as those who did not.

Similar results were reported by Supovitz and Turner (2000) who examined several thousand self-reports from teachers across the country involved in the LSC professional development work. They concluded that the quantity of professional development was strongly linked with inquiry-based teaching practice and investigative classroom culture. After 80 hours of professional development, teachers reported using inquiry more with additional hours leading to greater use of inquiry. Teachers appeared to have greater difficulty creating an investigative classroom culture as this required more than 160 hours of professional development.

Using a national probability sample of teachers and professional development providers involved in the Eisenhower professional development program, six characteristics that make inservice professional development effective were identified including the type of activity, duration, collaboration among teachers, content focus, active learning by participants and coherence with other professional development activities (Garet, Porter, Desimone, Birman, & Yoon, 2001; Porter, Garet, Desimone, & Birman, 2003). While these elements are in line with the key elements proposed by other scholars, these researchers argued that the duration of the professional development may be the most important characteristic as traditional and reform activities of the same duration "tend to have the same association with reported outcomes" (Porter et al., 2003, p. 27). Further clarifying the linkage between the duration of

professional development efforts and change in teacher practice, Garet et al. (2001) claimed that "professional development is likely to be of higher quality if it is both sustained over time and involves a substantial number of hours" (p. 933).

Classroom enactment

In addition to the critical impact that the duration of teacher change efforts has on practice, many have argued that teachers must also have the opportunity to enact the new practices in their own classroom (Anderson & Mitchner, 1994; Arora et al., 2000; Borko & Putman, 1995; Krajcik et al., 1994; Marx et al., 1997; Peers et al., 2003). Davis (2003) argued that "making strong links to personal learning and the classroom context are important for teacher change in beliefs and practice; this is true for both novice and experienced teachers" (p. 4). Blumenfeld et al. (1994), described how teachers concerns during implementation of a project-based science curriculum changed from enacting practices with fidelity to strategies for dealing with challenges and finally to beginning explorations of the underlying theory and congruent practices. The authors concluded that "enactments were crucial to the process of change; practice became a primary vehicle for the developing conceptions of features, associated challenges, and strategies for meeting them" (p. 545).

Current state of efforts to change practice

While much has been learned about what conditions are necessary for teacher change and how professional development efforts should be structured, researchers still report low quality professional development to be the norm. Porter et al. (1999), based on a longitudinal sample of 300 teachers involved in Eisenhower Professional Development program, found little change in teaching practice from 1996-1999, concluding that "given the usual low

quality and inconsistent nature of professional development in which teachers participated, it is perhaps not surprising that we find little change in overall teaching practice" (p. 9). In a separate review of the data on professional development activities that local school districts provide, it was found that 75-80% of teachers participated in traditional type professional development activities with the median number of contact hours for district activities being only 15 hours per year (Porter et al., 2003). The authors of the study concluded "our data shows that few features of high quality are prevalent in professional development activities" (p. 29).

However, while the history of teacher change efforts, and especially professional development, would make one doubt if they can be successful, Supovitz and Turner (2000) argued that "although professional development may not have realized its potential, it is still seen as the best bet for changing teaching practice" (p. 964). Richardson et al. (2001), in reviewing the literature on teacher change, concluded that "the long-term, collaborative and inquiry-oriented programs with inservice teachers appear to be quite successful in changing beliefs, conceptions and practices, although not all teachers respond well to such approaches." Making a similar argument, Weiss and Pasley (2006) asserted that broad agreement on the key features of effective professional development programs that lead to changes in teaching practices has been reached by researchers and that "while professional development designed according to theses principles does not guarantee that participating teachers will use what they learn to change their practice, it increases the likelihood that they will" (p. 2).

In summary, while efforts to reform science education often focus on the curricula to be used, evidence of the poor implementation of these curricula has led to the recognition that

teachers must be assisted in making the needed changes in their practice required to use inquiry-oriented instruction. Yet, traditional approaches to teacher change, characterized by top-down, skills training models, with strict adherence to implementing curricula in a specific prescribed manner, have failed to result in long-lasting change in teachers' practice. However, more recent efforts suggest that when teacher change is viewed as a long-term, non-linear process and where certain key elements are incorporated into teacher change efforts, including opportunities for teachers to enact new strategies in their own classrooms and to collaborate with other teachers allowing for reflection on the changes in their practice and beliefs, it is possible to create lasting change in teachers' practice. The role that teachers' beliefs plays in their practice and how this could influence change efforts is discussed in the following section.

Practice and Belief

Beliefs

Many definitions of beliefs have been constructed (Pajares, 1992). For example, Kagan (1992) argued that "teacher belief is broadly defined as tacit, often unconsciously held assumptions about students, classrooms, and the academic materials to be taught" (p. 65). Reflecting the consensus that beliefs influence practice, others have defined belief as "an understanding held by an individual that guides the individual's intentions for actions" (Hancock & Gallard, 2004, p. 281). In addition to the varying definitions, beliefs are also referred to by a variety of other terms, including attitudes, values, judgments, opinions, perceptions, conceptions, dispositions, internal mental processes, practical principles, and perspectives (Pajares, 1992).

Pajares (1992) argued that there is confusion as to what a belief is that centers around the distinction between beliefs and knowledge noting that in a review of the literature, “in all cases, it was difficult to pinpoint where knowledge ended and belief began” (p. 309). In general, he concluded that belief is based on evaluation and judgment, whereas knowledge is based on objective fact. For example, Crawford (2007) argued that beliefs “are highly subjective, have a significant emotional component, include attitudes, and are derived from significant episodes that one experiences” (p. 590), while knowledge is “empirically based, non-emotional, rational, gradually developed and well-structured”.

Ertmer (2005) provided further distinction between belief and knowledge, asserting that one may have knowledge of a particular concept, yet not believe it. For example, while a teacher may have knowledge that educational theory and research suggest that students learn science best when using inquiry, they may not believe that the students in their classroom will learn using inquiry.

While one might assume that teacher knowledge is key to effective teaching, Kagan (1992) argued that as there are no true educational truths for teachers to know, that “most of a teacher’s professional knowledge can be regarded more accurately as a belief” (p. 73). Indeed, it has been claimed that beliefs are far more influential than knowledge in determining how teachers teach (Kagan, 1992; Pajares, 1992).

Others have suggested that both beliefs and knowledge are equally important. Arguing that beliefs and knowledge may both play important roles in teachers practice, and that determining if a specific action was affected more by the teachers knowledge of belief is difficult, Crawford (2007) chose to use the term “view” to describe the interplay of knowledge and beliefs in making curricular decisions (p. 590).

An individuals beliefs are often difficult to determine as they are generally unstated and implied, and therefore must be inferred from what they say, intend and do (Kagan, 1990; Pajares, 1992). Teacher beliefs are often gathered using semi-structured interviews and analysis of the language teachers use to describe their thoughts and actions (BouJaoude, 2000; Kagan, 1990). In addition, while researchers have used changes in teachers metaphors describing their role in the classroom as a way to change their practice (Ritchie, 1994; Tobin, 1990; Tobin & Tippins, 1996), others have used changes in teachers metaphors to monitor changes in their beliefs (BouJaoude, 2000; Hand & Treagust, 1997).

A full review of the literature on beliefs is beyond the scope of this dissertation. Therefore, in order to provide relevant information on beliefs, the following items from a synthesis of findings on beliefs (Pajares, 1992) are provided.

- Beliefs are formed early and tend to self-perpetuate, persevering even against contradictions caused by reason, time, schooling, or experience.
- The earlier a belief is incorporated into the belief structure, the more difficult it is to alter.
- Belief change during adulthood is a relatively rare phenomenon, the most common cause being a conversion from one authority to another or gestalt shift. Individuals tend to hold on to beliefs based on incorrect or incomplete knowledge, even after scientifically correct explanations are presented to them.
- Beliefs about teaching are well established by the time a student gets to college.
- Individuals' beliefs strongly affect their behavior.
- Individuals develop a belief system that houses all the beliefs acquired through the process of cultural transmission.
- The belief system has an adaptive function on helping individuals define and understand the world and themselves.

- Knowledge and beliefs are inextricably intertwined, but the potent affective, evaluative, and episodic nature of beliefs makes them a filter through which the new phenomena are interpreted.

- Thought processes may well be precursors to and creators of belief, but the filtering effect of belief structures ultimately screens, redefines, distorts, or reshapes subsequent thinking and information processing.

- Beliefs are instrumental in defining tasks and selecting the cognitive tools with which to interpret, plan, and make decisions regarding such tasks; hence they play a critical role in defining behavior and organizing knowledge and information.

- Beliefs must be inferred, and this inference must take into account the congruence among individuals' belief statements, the intentionality to behave in a predisposed manner, and the behavior related to the belief in question.

In summary, beliefs appear to play an important role in the actions that people take, are formed early in life and are difficult to change. In addition, knowledge and beliefs interact in many ways with beliefs acting as filters through which affects the perception of all experiences and the knowledge that is gained.

Beliefs that teachers hold

Teachers have been found to hold a variety of different beliefs that are often complex and conflicting (Boulton-Lewis, Smith, McCrindle, Burnett, & Campbell, 2001; Bryan, 2003; Crawford, 2007; Peterson, Fennema, Carpenter, & Loef, 1989; Wallace & Kang, 2004). Smith (1990), based on teachers' interview responses about their views of what students should be learning, how learning occurs and their roles in promoting learning, developed three categories of teachers' conceptions of science teaching and learning: fact acquisition, content understanding, and conceptual change. Others, using both data on teacher beliefs and observed actions, developed similar categorizations that were: teacher-centered, conceptual and student-centered teaching style (Simmons et al., 1999).

In addition to holding a variety of beliefs as a group, individual teachers have also been identified who held multiple beliefs that were described as contradictory (Bryan, 2003), competing (Wallace & Kang, 2004), or as forming two dualities (Hancock & Gallard, 2004). Several studies noted that teachers may hold a mixture of teacher-centered and student-centered beliefs with the teacher centered beliefs often being dominant and affecting practice (Bryan, 2003), and that a teacher's beliefs may shift toward either of the poles during efforts to implement inquiry-based strategies; that is, they may become more student-centered or more teacher-centered beliefs (Hancock & Gallard, 2004).

Relationship between beliefs and practice

In reviewing the literature on beliefs, Pajares (1992) concluded that beliefs are "the best indicators of the decisions that individuals make throughout their lives" (p. 307). Other scholars have argued that teachers' beliefs play a major role in the decisions that are made about curriculum and instructional tasks (Anderson & Mitchner, 1994; Borko & Putman, 1995; Crawford, 2007; Davis, 2003; Kagan, 1992; Pinto, 2005; Tobin et al., 1994; Wallace & Kang, 2004). For example, Crawford (2007), in a study of five prospective science teachers, asserted that "a prospective teacher's set of beliefs about pedagogy, school, students learning, and the nature of scientific inquiry may have been the overriding factor influencing choice and eventual success in teaching science as inquiry" (p. 608).

Numerous studies have suggested that teachers' beliefs typically reflect the actual practice that occurs in the classroom (Boulton-Lewis et al., 2001; Haney, Lumpe, Czerniak, & Egan, 2002; Luft, Roehrig, & Patterson, 2003; Richardson, Anders, Tidwell, & Lloyd, 1991; Yerrick et al., 1997). Kagan (1992) concluded that "empirical studies have yielded quite consistent findings: A teacher's beliefs tend to be associated with a congruent style of

teaching that is often evident across different classes and grade levels" (p. 66). For example, Peterson et al. (1989), based on teacher self-reports of their practice and interview data regarding their beliefs and knowledge about teaching and learning, concluded that there were differences in practice between teachers whom they found to have more cognitively based perspectives compared when compared to teachers who had a less cognitively based perspective. Specifically, the teachers with a more cognitively based perspective made extensive use of word problems in teaching addition and subtraction, spent more time developing children's counting strategies before teaching number facts, and developed a knowledge of the students problem-solving strategies by observing the children solve problems rather than relying on formal assessments.

However, discrepancies between teachers belief and their actual classroom practice have been described by several researchers (Murray & MacDonald, 1997; Simmons et al., 1999; Kang & Wallace, 2005); in most cases the teachers espoused student-centered beliefs but were determined to have teacher-centered instructional practices. For example, while a substantial majority of college lecturers beliefs reflected their role as either facilitators or student supporters, their practices were found to be based on lectures and tutorials focused on disseminating information and checking knowledge (Murray & MacDonald, 1997).

Kang and Wallace (2005), in a study of teachers who were found to hold a range of epistemological beliefs, documented differences in the congruence of belief and practice depending on the type of beliefs held. For those with naïve epistemological beliefs, their beliefs were clearly reflected in their teaching practices. Yet there was not always congruence of practice for teachers with more sophisticated beliefs. The authors argued that this might be due to the interaction of the teachers' beliefs with the particular teaching

context and instructional goals, such as mandated curricula and end of grade tests, which are often beyond teachers' control.

Beliefs change as a focus of reform efforts

As beliefs may affect teachers' practice in the classroom, reformers have argued for attention to teachers beliefs during efforts to change their practice (Anderson & Helms, 2001; Beck et al., 2000; Borko & Putman, 1995; Krajcik et al., 1994; Richardson & Placier, 2001). Gess-Newsome (2003 as cited in Johnson, 2006) argued that "the nature of beliefs held by teachers may ultimately make the difference in the success of failure of the current wave of reform" (p. 11).

Beliefs may act as filters such that teachers interpret the messages they receive about changing their practices in ways not intended, which ultimately affects how new instructional tools are used in the classroom (Borko & Putman, 1995; van Driel, Beijaard, & Verloop, 2001; Yerrick et al., 1997). For example, for a teacher whose beliefs reflect a didactic approach to teaching and learning, small groups may be viewed simply as a new arrangement for students to work independently. In contrast, for a teacher whose beliefs reflect a more constructivist approach to teaching and learning, small groups may become a place for students to work together to solve problems (Borko & Putman, 1995).

Numerous research findings support the claim that teachers' often hold beliefs that are contrary to what is known about effective teaching and can reduce the effectiveness of the implementation of new curricula (Fraser, 1998; Kelly & Staver, 2005; Roehrig & Kruse, 2005; Wallace & Kang, 2004). For example, in case studies of two middle grade teachers implementing a constructivist-based curriculum, it was found that both teachers believed that the most important student outcome was factual knowledge, that students learn best by drill

and practice and that students require a great deal of explicit direction (Cronin-Jones, 1991). The researcher argued that these beliefs prevented the teachers from implementing the curricula as intended and concluded that "in order to ensure more congruence between intended and implemented curricula, developers should put more effort into determining and considering existing teacher belief structures before developing new curricula" (p. 248).

Given the arguments and evidence which indicate that teachers' beliefs affect their classroom practice, it would seem logical that change in teachers' beliefs should precede change in their practice and thus should be the primary focus of professional development efforts. Guskey (1986, 2002) asserts that this has indeed been the case for the majority of traditional professional development efforts. However, he contends that rather than leading to successful teacher change, this focus on belief change has been the primary reason that much of the professional development has failed to produce changes in teachers' actions.

Several studies have reported that while teachers' beliefs were changed, their actual practice did not improve (Lee, Hart, Cuevas, & Enders, 2004; Luft, 2001; Simmons et al., 1999). For example, Prawatt (1992) reported that the teacher involved in the study made important changes in her views about mathematics teaching, although not to a constructivist perspective, during implementation of a new curriculum, yet this resulted in very few changes to her practice. Similarly, Vacc and Bright (1999) reported that while elementary teachers beliefs about mathematics instruction had significantly changed toward a constructivist orientation during the undergraduate program, their use of children's mathematical thinking during instructional planning and teaching was limited.

Guskey (1986, 2002) argued that rather than change in belief preceding change in practice, teachers typically try out new practices keeping those that work and abandoning

others. Thus he postulated that teachers' beliefs do not change until they have seen improvement in student learning outcomes due to the new practices. Guskey claimed that the evidence from studies on teacher change suggests that "improvement (positive change) in the learning outcomes of students generally precedes and may be a prerequisite to significant change in the beliefs and attitudes of most teachers" (1986, p. 7). For example, Huberman and Miles (1984) reported that teachers often did not commit to the curriculum implementation project until after they had gained practice mastery, suggesting that the teachers did not believe that it would work until they had seen it. Other researchers have reported similar results where change in teachers' practices seemed to precede change in beliefs (Arora et al., 2000; Hand & Treagust, 1997; Wood, Cobb, & Yackel, 1991).

However, change in teacher practice has not always been reported to precede change in belief. Richardson et al. (1991) argued that changes in belief appeared to precede changes in practice in a case study of a teacher implementing new reading comprehension strategies. They found that the teacher involved in the study expressed a constructivist view of reading comprehension initially whereas her practice focused on the use of basal readers and literature; only later did her practice later change to reflect a more literature based approach.

Simmons et al. (1999) documented cases of belief change, in the absence of corresponding change in practice, where the teachers' beliefs moved from being more student-centered to more teacher-centered. The researchers found that many beginning teachers, who initially espoused a student-centered belief but were observed to have teacher-centered instructional practices, changed their beliefs over a period of three years to become more congruent with their practice, that is, their beliefs became more teacher centered to match their practice. The authors suggested that the teachers' beliefs changed rather than

practice due to constraints encountered in school, including the need to have classroom control and gain tenure. As these teachers could not afford changes in practice, their beliefs changed to become more congruent with their practice.

Luft (2001) found differences in the extent to which the beliefs or practices changed in 14 secondary science teachers involved in the professional development program based on the amount of experience teaching. As a group, the teachers were found to have exhibited statistically significant changes in their practice, yet there was no significant change in their beliefs. However, upon closer examination, it was found that the induction teachers changed their beliefs more than their practices; in the end their beliefs and practices became congruent. Some became more student-centered in their beliefs and were using inquiry in the classroom, whereas others became more teacher-centered in their beliefs and were not using inquiry.

In contrast, the experienced teachers changed their practice more than their beliefs. Luft suggested that it may have been easier for the experienced teachers to change their practice as the professional development program may have supported initial changes in practice that were consistent with their current beliefs. Luft also argued that creating further change in the experienced teachers' practice might require change in belief.

While many researchers have argued that either change in practice or belief should be the primary focus of teacher change efforts, others argued that the focus should be on both belief and practice (Johnson, 2006; Richardson et al., 1991). Richardson et al. (1991) reported that teachers had been observed trying to make changes in their practice but were unsuccessful as they did not understand the underlying theory. Conversely, teachers were observed who had

developed different ways of thinking about teaching, but did not know how to translate these into action. Based on these observations they suggested that:

> One could conclude, then, that genuine changes will come about when teachers think differently about what is going on in their classrooms, and are provided with the practices to match the different ways of thinking. The provision of practices without the theory may lead to misimplementation or no implementation at all, unless teachers' beliefs are congruent with the theoretical assumptions of the practice. Further, programs in which theory is discussed and which focus on changing beliefs without proposing practices that may embody those theories may lead to frustration. (p. 579)

In summary, while there is no clear consensus as to the relationship between teachers' knowledge and beliefs, there does seem to be general agreement that knowledge and beliefs interact and that these beliefs teachers' hold about teaching, learning and many other areas affect the actions that they take in the classroom. As teachers' beliefs are viewed as playing an integral part in the actions taken, many have argued that change in teachers' beliefs is an important component of any effort to change practice. However, it is unclear whether to focus on change in beliefs that may then lead to change in practice, or to change practice first to be followed by change in belief. It may be that attention must be paid to changing both teachers' beliefs and practice at the same time, as to take action without understanding or to understand but now know what actions to take are both ineffective choices.

The Science Writing Heuristic Approach

Taking into the account the crucial role of language in learning, and the potential benefits of writing as a way to learn in particular, the Science Writing Heuristic (referred to hereafter as the SWH) (Keys et al., 1999) was developed as an inquiry-based alternative to the traditional laboratory report. The SWH was envisioned as a tool to be used by teachers as a framework to guide designing classroom activities in a manner more consistent with inquiry,

specifically to “promote connections among investigation questions, procedures, data, evidence and knowledge claims that may not initially be apparent to students” (Keys et al., 1999, p. 1065). A scaffolded approach is provided whereby the students use the heuristic, or template, to develop explanations with their peers; in doing so students generate questions that they are interested in and can test, conduct experiments to answer these questions (developing their own tests when possible), and construct claims that are supported by the evidence collected.

Emphasizing the role that argument plays in developing scientific knowledge, a key outcome with use of the SWH is that students are encouraged to make connections among their observations, claims and evidence. In developing claims for what has occurred in their investigations, students are “asked to describe a pattern, make a generalization, state a relationship, or construct an explanation” (Keys, 2000, p. 680). Students are then required to provide data and evidence to support their claim.

Based on the well-supported inquiry practice in which students first engage with the concept to be learned before being exposed to the currently held scientific conception, it is only after developing claims and evidence that students are asked to read how “official” sources, such as the textbook, explain the concept. Finally, students are asked to reflect on how their ideas have changed.

Implementing the SWH requires that teachers take a more student-centered approach to teaching as “the heuristic requires the adoption of a negotiated, meaning-making pedagogy by the teacher to assist students in constructing understanding of the concepts under review” (Hand et al., 2004, p. 134). To assist teachers in implementing the SWH, a teacher template was also developed that includes a series of suggested activities to engage students in

meaningful thinking, writing, reading, and discussion about concepts involved in the laboratory activity. For example, included in the teacher template are suggestions for determining students' prior understanding and facilitating several phases of discussion and negotiation of meaning in both small group and whole class settings.

While the SWH is in one sense a tool to assist students and teachers in creating conditions conducive to learning through inquiry, the pedagogical practices and the underlying learning theories upon which it is built are congruent with those that promote learning, regardless of the activities being undertaken. Therefore, the SWH has also been referred to as an approach, indicating that teachers should use the pedagogical practices throughout all aspects of their instruction, not only when engaging students in laboratory exercises (Akkus, Gunel, & Hand, in press).

Student outcomes from using the SWH approach

Research studies on the effects of use of the SWH approach on student outcomes in middle school, high school and college settings have indicated that students who used this approach improved their understanding of science concepts, as demonstrated by scoring significantly higher on conceptual questions of science knowledge, compared to students in control classes using traditional instruction characterized by use of textbooks and traditional labs (Hand et al., 2004; Hohenshell et al., 2002; Keys et al., 1999; Keys et al., 2001; Rudd et al., 2001). In addition, qualitative studies have indicated that the SWH approach promotes metacognitive thought about laboratory activities the students undertake, reflection about the knowledge generated, and improved understandings of the relationship between questions, claims and evidence (Wallace et al., 2007).

Initial research on use of the SWH approach utilized teachers who had previously demonstrated a thorough understanding of the use of inquiry-based teaching and learning strategies (Keys et al., 1999). Thus, during initial studies that were focused on student outcomes, it was assumed that the teacher would implement the SWH in a manner congruent with the developer's intentions. Yet not all teachers have been able to successfully implement the SWH approach in their classrooms. More recent studies using larger numbers of graduate teaching assistants and inservice k-12 teachers with little experience using inquiry have suggested that student achievement is also affected by the extent to which the instructor effectively implements the SWH (Omar et al., 2002; Omar, 2004).

In an effort to begin to determine what essential characteristics distinguish teachers who implement the SWH effectively from those who do not, sixteen teachers were observed as they implemented this approach (Omar, 2004). Results from this study suggest that there were four key indicators that would determine the extent to which the SWH was effectively implemented; the degree to which the teacher: a) promotes student to student dialogue to increase the public sharing of knowledge in the class, b) focuses on the big ideas (both in planning and during instruction), c) uses effective questioning and d) creates an effective learning environment through effective classroom management. These indicators are similar to those that were previously discussed in reviewing the literature on effective teaching.

While there have been numerous research studies on the role that teachers beliefs play in the effective implementation of inquiry approaches, no studies regarding teachers' beliefs during implementation of the SWH approach have been conducted. As such, part of this study will focus on this question.

In summary, the Science Writing Heuristic is an approach to the use of inquiry in the classroom that emphasizes the use of language and argumentation as students construct personal meaning through social negotiation. Research studies on the use of the SWH approach are in general agreement with many of the previous findings regarding inquiry, including that there are numerous positive outcomes for students and that the teacher plays a crucial role in the effective implementation of inquiry. Yet the effect of teachers' beliefs on how effectively they implement the SWH approach has yet to be conducted and will form part of this study.

Summary

This chapter has addressed the relevant literature regarding efforts to assist teachers in utilizing inquiry-oriented instruction that forms the theoretical framework of this dissertation. Inquiry once again plays a central role in efforts to reform science education with the lofty goal of developing in students an understanding of both fundamental science concepts and the processes of science in addition to being able to use the processes of science. Due to the difficulties that teachers have experienced in implementing inquiry-oriented curricula, assisting teachers in changing their practices has become a key component of efforts to improve science education. Yet, initial efforts, characterized by top-down, skills training models, with strict adherence to implementing curricula in a specific prescribed manner, failed to result in long-lasting change in teachers' practice. However, more recent efforts suggest that when teacher change is viewed as a long-term, non-linear process and where certain key elements are incorporated into teacher change efforts, including long-term opportunities for teachers to enact new strategies in their own classrooms and to collaborate with other teachers allowing for reflection on the changes in their practice and beliefs, it is

possible to create lasting change in teachers' practice. Finally, beliefs are claimed to play a central role in the actions that individuals take and thus play a key role in efforts to assist teachers in improving their practice.

CHAPTER 3. RESEARCH METHODOLOGY

Introduction

This chapter provides a description of this study's design, including the context in which the study took place and a justification for the design, based on the current literature in research methods. Therefore, this chapter is divided into three main sections. The first provides the context of this study, including the research questions, participating teachers and the professional development program. The second provides the justification for the particular qualitative methods used to investigate the research questions. In the final section the qualitative research design of this study is presented, including data collection and analysis.

A major tenet of current science education reform is that many inservice teachers require professional development assistance to make the necessary changes in their practice in order to effectively implement inquiry-based instruction. In addition, there is a growing recognition that teachers' beliefs, defined by Hancock and Gallard (2004) as "an understanding held by an individual that guides the individual's intentions for actions" (p. 281), play an important role in the extent to which teachers can effectively implement inquiry-based instruction and the degree to which their practice may change during professional development. Therefore, this study was conducted in order to better understand the extent to which a group of three teachers in a small rural school district changed their practice, and the role that their beliefs about teaching and learning played in the change process, as they implemented the Science Writing Heuristic (SWH), an inquiry-based approach to learning and teaching science. In order to support these teachers, in-class professional development assistance was provided by

a retired master teacher experienced in using inquiry methods and assisting teachers in making changes so that they can effectively implement inquiry.

The two research questions investigated in this study are:

1. What changes occurred in teachers' pedagogical practices, and beliefs about teaching and learning, as they implemented the SWH approach while receiving support in a professional development program?
2. What was the relationship between the teachers' beliefs about teaching and learning and changes in their practice as they implemented the SWH approach while receiving support in a professional development program?

Context of the Study

Recruitment of the teachers

Researchers at Iowa State University received a grant from the Iowa Department of Education to conduct a three-year study on the implementation of the SWH approach in elementary classrooms and the effect that this has on students' performance. In order to gather data regarding teacher implementation of the SWH approach in rural areas, Tom, a retired science teacher experienced in professional development efforts and who had previously been involved with research into SWH approach, was asked to find a group of teachers to work with. Tom contacted a group of three teachers in a small rural school district in northeastern Iowa that he had previously worked with whom all agreed to participate.

The teachers initially agreed to participate in the professional development program but without any direct research focus on their implementation. Thankfully for this researcher, they did subsequently agree to allow for their implementation of the SWH approach to become a focus of research. However, as this was seen as an additional task beyond their

initial commitment of time, it was decided to minimize requests for the teachers to do additional work related to this research study. For example, while it would have been desirable to have the teachers keep written journals, this request was not made.

The three teachers involved in this study received no stipend for participating and were not mandated by their system to participate in this program. Thus their participation was considered to be purely voluntary.

Participating Teachers

At the time of this study, Martha was a grade four and five teacher with fifteen years of teaching experience and had taught science for twelve years. She had a BA in Elementary Education and an MA in Educational Technology. Her initial training for teaching science included one science methods course and one biology class. For the previous five years, she had participated in an NSF-sponsored professional development program designed to promote the use of inquiry in the classroom. In addition to voluntarily choosing to implement the SWH approach to inquiry this year, the elementary school where Martha teaches had mandated the implementation of the Reading First program. This program emphasized the use of non-fiction books to help teach content and required the teachers to keep daily records or how much class time was devoted to language activities.

Fred was the grade six and seven science teacher and had approximately three years of experience teaching science. He had a BS in biology and conservation management and entered into education through a non-traditional pathway as a teacher associate; Fred worked for several years helping in the ‘resource room’ with students who had disciplinary problems at the school. During this time, he began and completed work to receive a teaching endorsement in science by completing education specific courses requirements in a normal

two year program that he completed in one year. He also participated for a short period in the same NSF sponsored professional development program as Martha, however, this was interrupted by a leave of absence due to military deployment.

Sofia was the grade eight science and math teacher in her first full year of teaching. She had a BA in biology education and served as the substitute teacher for Fred while he was deployed with the military. Sofia also had limited experience with the same NSF sponsored professional development program that Martha and Fred had been involved in.

Martha taught at the elementary school while Fred and Sofia taught at the middle school. Whereas Martha taught her elementary students each day, the middle school was on an alternating block schedule such that Fred and Sofia taught each class of students every other day.

In order to ensure confidentiality and alleviate any potential ethical issues, the teachers were asked to complete all required informed consent forms prior to participation in this study. Students were also asked to complete consent forms since this study involved videotaping of lessons.

Professional growth program

Support for teachers involved in studies of the SWH approach has typically been supplied by either the researchers who developed the approach or graduate students under their supervision. However, with the group of teachers involved in this study, the majority of support was provided by Tom, a retired science teacher with thirty-three years experience as a teacher. Tom was involved in several reform-based projects while teaching and had spent the past five years assisting in the professional development component of a NSF sponsored

program designed to promote the use of inquiry in rural classrooms. He had also been involved in research on the implementation of the SWH approach for the past three years.

However, Dr. Brian Hand, one of the scholars who developed the SWH approach, maintained contact with Tom throughout the duration of this study, talking to him at least once a week. In this way Dr. Hand was able to monitor the progress that the teachers were making and make suggestions for actions that Tom could take to further assist the teachers. Thus, the professional development Tom provided to the teachers was similar to that provided to teachers involved in other studies of the SWH approach.

The professional development that was provided met many of the characteristics of effective professional development (Davis, 2003). One of the unique features of this professional development effort is that an experienced mentor was used to provide in-class support to the teachers. Initially, training was provided in the design and effective implementation of lessons using the SWH approach including discussion of the types of activities to engage students in, the role of questioning, and student to student dialogue. Tom then assisted the teachers in developing lessons for the first unit using the SWH approach. Effective implementation of crucial aspects of the SWH approach, including questioning and student discussion, was modeled by Tom when possible. Based upon observation of the teachers practice, assistance and suggestions for change in practice were based, to the extent possible, on each teacher's current knowledge and practices. For example, as Tom had worked with Martha previously on questioning practices, he chose to focus her efforts on integrating student to student discussion into her practice. Further feedback was provided after subsequent observations creating a cycle of observation, feedback and further observation. Finally, this professional development program provided a long-term experience

as it lasted nine months with many contact hours between the teachers, their students, and Tom.

While the focus of this study was on individual teachers in their classroom, the school district created a barrier to changing practice that could not be overcome. Many scholars have argued that collaboration among teachers is a critical factor in successful professional development efforts as this provides opportunities to share successes and struggles with others (Davis, 2003; Marx et al., 1997). Yet as a result of the low number of students in the schools, each teacher was the sole science instructor for at least one grade level. Thus the three teachers involved in this study were responsible for science instruction in grades 3-8 at two different schools. Therefore, there were minimal opportunities for the teachers to collaborate, a condition that was beyond the authority of the teachers of professional development providers to overcome.

Tom began his work with the teachers by holding an initial work-session after a regularly scheduled inservice day prior to the start of the school year. During this time Tom and the teachers discussed the theoretical underpinnings of the SWH approach, what constituted activities that would fit the SWH approach, the types of questions kids might want to explore, the criteria that would determine if a question is testable, and did some inquiry type activities to demonstrate how the SWH process works and to give teachers personal experience with it. In subsequent work with the teachers, he emphasized other key factors in the effective implementation of the SWH, including the use of effective questioning skills and the importance of and ways to facilitate student dialogue. In addition, several articles about the use of the SWH and effective questioning, and copies of the book *Science Workshop* (Saul, 1993) were read and discussed by Tom and the teachers.

During the first semester, Tom made frequent trips to the schools to work with the teachers; for example, he met with each teacher eight times during the month of September. During these visits, he often modeled the use of the SWH for the teachers, teaching parts of, or entire lessons, for one class period and then having the teacher teach the next class while he observed. He also spent time discussing concerns they had, providing advice to help them with the type of activities they could use, and specific pedagogical aspects that they needed to work on. To assist the teachers in assessing their practice and reflect on why they were taking certain actions, Tom spoke with the teachers after observation about key events he had observed. For example, during one lesson he noticed that Fred allowed the male students to dominate discussion and spoke with him about why this had happened and what actions could be taken to prevent this. However, it should be noted these discussions were not designed to change the teachers' beliefs, as Tom was directed to work with the teachers on only improving their pedagogical practices.

During the second semester Tom reduced the amount of time he spent modeling lessons for the teachers and focused more on observing their teaching and providing advice on areas that they needed to work on to improve their implementation of the SWH approach. This also provided an opportunity to observe the teachers practice without the direct assistance from Tom in planning and modeling lessons that had occurred earlier.

In addition to Tom's work with the teachers, Dr. Hand held an Iowa Communication Network session with the teachers several weeks into the school year. During this session Dr. Hand provided a general overview of the SWH approach, including the role of claims and evidence and student dialogue, and discussed concerns the teachers had about using the SWH approach. In December, Dr. Hand and this researcher traveled to meet with the teachers and

discuss further the implementation of the SWH approach. Both the teachers' successes and struggles were discussed at this time.

In summary, throughout the year Tom and others provided the teachers with information regarding areas that had been identified as crucial to effectively implementing the SWH approach, suggestions regarding areas of their practice that had been observed to need improving, and overall support including providing ideas for activities. However, the teachers were not forced to make any changes that were suggested and throughout the study it was their choice as to what actions to take.

General description of how the year progressed

Since the teachers did not become involved in this study until the beginning of the school year, they were given time to learn about the SWH and to practice the skills needed to effectively implement the SWH, such as questioning. Martha began using certain aspects of the SWH approach immediately, such as students developing questions they had about science. She began teaching a unit with the approach within two months. Fred and Sofia spent approximately three months before they began to use the approach to develop a unit.

During the second semester, each teacher was asked to use the SWH approach for back-to-back units. The students were to complete at least three activities using the student SWH template followed by a summary writing activity. Martha chose to use the SWH approach with just her fourth grade during the first unit. During the second and subsequent units, the SWH approach was used with both classes. Fred chose to use the SWH approach with only his seventh grade class during the first unit and did not complete a second unit, rather opting to implement a cooperative learning unit with a language teacher. Sofia used the SWH for

both units with her eighth grade science class, with the second unit on forces and motion lasting approximately four months.

In addition, as Fred and Sofia taught multiple sections in each grade level, they were asked to have one class serve as a control while the other sections used the SWH approach. The rationale for this was that implementing new instructional methods is difficult and having one class as a control provides an opportunity for the teachers to teach in a manner that they are accustomed to. This also provided an opportunity for Fred and Sofia to reflect on differences in the pedagogical practices required and the potential impact on student outcomes. However, for the purposes of this study, analysis was only conducted on observations of classes in which the SWH approach was used as the teachers would be expected to exhibit practices congruent with inquiry-based teaching in the treatment classes and not the control.

Qualitative Research

While both quantitative and qualitative research traditions have provided a deeper understanding of educational processes, many have argued that these approaches to research have fundamentally distinct paradigms upon which they are based. Glesne (1998) claims that quantitative research is based on a positivist belief which assumes that a fixed, measurable reality exists external to people, which in social research has resulted "in efforts to discover a set of causal laws that can be used to predict general patterns of human behavior" (Esterberg, 2002, p. 2). In contrast, qualitative research is claimed to be based on an interpretivist, or constructivist, belief which assumes that reality is socially constructed as humans create meanings for the things they interact with (Esterberg, 2002; Glesne, 1998); therefore reality "is not the fixed, single, agreed upon, or measurable phenomenon that it is assumed to be in

positivist, quantitative research" (Merriam, 2002, p. 3). Thus, the goal of qualitative research is to "reveal the meanings that people ascribe to particular events or activities" (Esterberg, 2002, p. 2), with the goal of developing an understanding of social processes in the context they occur which requires that one have in-depth interaction with participants over long periods of time (Glesne, 1998).

Qualitative research approaches have proven especially useful in education in cases where the goal is to get "detailed information about implementation, to identify the nuances of subjective understanding that motivate various participants in a setting, [and] to identify and understand change over time" (Erickson, 1999 p. 1155). Therefore, a qualitative research design was chosen as this enabled the collection of data and generation of findings concerning the teachers' implementation of the SWH approach and their beliefs about teaching and learning that may have affected the degree to which they were able to successfully implement the SWH approach.

Specifically, an interpretive qualitative research design was used for this study as this provides a way to learn "how individuals experience and interact with their social world, [and] the meaning it has for them" (Merriam, 2002, p. 4). In addition, as a particular group of teachers at a specific time is being studied, a case study design was used to provide an opportunity to describe these teachers in depth (Merriam, 2002). While acknowledging that the generalizability of a study involving only three teachers implementing a specific program is a valid concern, as Merriam (2002) argued "It is the reader, not the researcher, who determines what can apply to his or her own context" (p. 179).

Reliability and Validity

There are three main sources of data that may be collected and analyzed in a qualitative study: observation of participants, interview with the participants, and documents relating to the focus of the study (Glesne, 1998; Merriam, 2002). As the researcher is typically the primary instrument for data collection and analysis, concerns have been expressed about the internal validity or degree to which the conclusions generated are congruent with reality, the reliability or degree to which the conclusions are consistent with the data collected and the external validity, or the degree to which the conclusions can be generalized to other situations (Esterberg, 2002; Maxwell, 2002; Merriam, 2002; Schofield, 2002). In addition, while there are well-developed and accepted methods to ensure validity and reliability in quantitative research, there has been much debate and discussion in the literature regarding these areas in qualitative research (Merriam, 2002).

However, many have argued that the apparent weaknesses of qualitative research are actually strengths. For example, Merriam (2002) argued that the internal validity of a qualitative study may be increased, in comparison to quantitative studies, as the researcher is the primary instrument of data collection and analysis. She suggested that as the "interpretations of reality are accessed directly through observations and interviews" (p. 25) rather than through the use of quantifiable methods, such as the use of predefined surveys, the resulting conclusions are closer to reality and thus have greater internal validity.

The perceived weakness regarding the reliability of qualitative studies may be attributed to the differing meanings of the term in the two research approaches. Whereas in quantitative research, reliability often refers to the extent to which research results can be replicated, in quantitative research it refers more to the extent to which the results are consistent with the

data collected. In discussing the differing meanings of reliability, Merriman (2002) asserted that, “rather than insisting that others get the same results as the original researcher, reliability lies in others’ concurring that given the data collected, the results make sense – they are consistent and dependable” (p. 27).

There are also differences in the meaning of external validity in the two approaches. While in both research traditions external validity refers to the extent to which conclusions can be generalized to larger populations, due to differences in the number of research subjects involved in each type of study, how this is applied is dramatically different. In quantitative research large numbers of randomly selected subjects allow for the conclusions to apply to large groups. Yet, in typical qualitative studies with a small number of subjects studied in particular contexts, it is not possible to apply the conclusions to large populations.

However, this is seen as a strength by some who have argued that “The general lies in the particular; what we learn in a particular situation we can transfer to similar situations subsequently encountered” (Merriam, 2002, p. 28). In addition, Schofield (2002) in discussing the differing outcomes related to external validity argued that, “The goal is not to produce a standardized set of results that any other careful researcher in the same situation would have produced. Rather it is to produce a coherent and illuminating description of and perspective on a situation that is based on and consistent with detailed study of that situation” (p. 174). In order to accomplish this, the reader must be given enough detail of the study’s context and data to “adequately and convincingly support the findings of the study in the form of exact quotes, episodes from observations and references from documents” (Merriam, 2002, p. 21), often referred to as “rich, thick description”.

Finally, both internal validity and reliability can be strengthened in a qualitative study by the use of multiple research strategies and methods of analysis, often referred to as triangulation (Erickson, 1998; Esterberg, 2002; Merriam, 2002). As Esterberg (2002) asserted, the use of triangulation is recommended as "different data collection strategies have different strengths and weaknesses, research designs that include multiple research strategies tend to be the strongest" (p. 37). By collecting multiple sources of data and using multiple methods to analyze the data, one can draw more credible conclusions (Erickson, 1998).

In this study, the internal validity and the reliability of the findings were strengthened through triangulation allowing for credible conclusions to be drawn. For each teacher evidence was used from their observed pedagogical practice, interview responses, metaphors describing their role in the classroom, comments made when working with Tom, and other sources of data to support and strengthen the internal validity and reliability of the conclusions regarding their practices and beliefs. The external validity of this study was increased by the use of rich, thick descriptions, including numerous quotes from the teachers in this study, in addition to descriptions of their observed pedagogical practices and excerpts from other sources of data. Additional details regarding the validity and reliability of this study are provided in the section on data analysis.

Design of the Study

Data Collection

Videotaped Observations

The primary goal of this study was to assess the extent to which the teachers changed their pedagogical practice over time as they implemented the SWH approach. As the research location was approximately three hours from ISU, multiple on-site observation visits were

problematic. As an alternative to on-site observation, video recordings of the teachers were used to make a permanent record of their practice. This practice has both advantages and disadvantages compared to on-site observation.

A key disadvantage to on-site observation is that the observer must focus on certain items to observe and therefore is not able to create a record of all actions that occur, thus limiting the amount of evidence that can be collected (Jaeger, 1993; National Research Council, 2001; Stigler, Gallimore, & Hiebert, 2000). In contrast, one of the key advantages of using recorded observations is that the tape is a permanent, concrete record that can be reanalyzed later to check findings, search for different patterns, and allow the researcher to focus full attention on certain aspects of the classroom during each viewing, increasing the amount of detail that can be gained (Jaeger, 1993; National Research Council, 2001; Plowman, 1999; Stigler et al., 2000).

However, there are significant disadvantages to the use of videotaping as this method imposes a different limitation in that the camera only records what is in the frame, and can not scan the room as easily to take in all that is happening at one time (Stigler et al., 2000). In addition, the audio microphone has less sensitivity and selectivity than human hearing and makes it difficult to focus attention on a single conversation in a noisy classroom (Roschelle, 1999).

In addition, concerns have been expressed that a teacher may not exhibit their typical behaviors when being videotaped. For example, a lesson may be planned and behaviors exhibited that a teacher believes the observers wants to see. However, Stigler et al. (1999) concluded, based on teacher self reports, that the TIMMS Videotape Classroom Study had captured a fairly representative sample of what happens in the classrooms studied. Thus, it is

assumed in this study that the teacher behaviors observed are those that the teacher would use regardless of being observed.

In this study, one tape was made of each teacher within the first six weeks of the school year to serve as a baseline of what each teacher's pedagogical practice was prior to implementation of the SWH approach. While it is possible that a single observation could provide an anomalous description of a teacher's practice, other studies of teacher practice using the same instrument described in the data collection section have also used a single observation to record teachers' practice (Pasley et al., 2004; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Once the teachers began using the SWH approach, videotapes were made as often as possible. While it was originally planned to record a lesson each of the three times the teachers did an SWH activity per unit, for a total of six additional tapes, this did not occur for several reasons: the teachers did not do as many activities with the SWH template as planned, Tom spent much more time modeling and working with the teachers during the first unit than originally planned and was therefore unable to videotape lessons, and, during the second unit Tom was unavailable to record the teachers for approximately one month. However, during this time the teachers were able to record some lessons themselves or with the assistance of their teacher associates. It should also be noted that in Martha's case, on two occasions, several successive lessons were recorded. For each set of successive lessons, analysis was performed and reported as though these were a single lesson.

Interviews

While observation through the use of videotapes provided a visual record of the teachers' pedagogical practice at various times throughout the year, it was also possible that the

teachers themselves could provide information about their practice and any changes they believed to have occurred. In addition, it has been argued that teachers' beliefs cannot be assessed directly as beliefs are often held unconsciously and teachers may be unable to express their beliefs in verbal terms or may be unwilling to air unpopular beliefs (Kagan, 1990). Thus, it has been suggested that teachers' beliefs must be accessed indirectly, through means such as extended interviews, from which the underlying beliefs are then inferred.

Therefore, to gain an understanding of the teachers' beliefs about teaching and learning that may affect their implementation of the SWH approach, and the process of implementation from the teachers perspective, partially-structured interviews (Krathwohl, 1997) were conducted with each teacher at approximately five and eight months into the study. This approach was chosen as Seidman (1998) has suggested that, "at the root of in-depth interviewing is an interest in understanding the experience of other people and the meaning they make of that experience" (p. 3). In turn, the purpose of such interviewing is to weave a story about an event an individual has experienced. Interviewing the teachers enabled the development of a link between the practices that were observed and the teachers' perceptions of what occurred and the reasons they took specific actions.

Use of a partially structured interview structure provided flexibility in the interview process as the researcher developed questions prior to the interview, yet determined the order questions were asked during the interview. In addition, questions were added or modified as needed based on the respondents answers (Krathwohl, 1997). An interview protocol was constructed with a series of open-ended questions which allowed the teachers to choose the most salient features of their experience and respond in their own words (see Appendix A for a sample of questions asked). This is an approach considered by many to be the most

effective type of questions to ask in an interview (Dilley, 2000; Patton, 1990; Seidman, 1998). Before conducting the interviews each respondent was e-mailed the questions to allow time for additional reflection on their responses, and in both cases Martha also provided written comments to the interview questions.

The initial interviews lasted approximately one hour. While the questions in the interview guide were grouped and arranged in what seemed a logical order, the respondents' lead was followed in choosing the order of questions during the interview and when to use additional probing questions to gain further understanding. Based on analysis of the initial interviews and additional questions derived from a continuing review of the relevant research literature regarding teacher change, a second interview protocol was developed to further elicit the teachers' perceptions of changes in the practice and their beliefs about teaching and learning. To facilitate analysis of the interview data, all interviews were recorded and transcribed.

In addition to oral interviews, several other forms of interviews were conducted. The teachers were asked to provide short written answers to several questions relating to teaching and learning. When possible, audio recordings were made when Tom was working with the teachers in order to gain a better understanding of what occurred and to provide an additional source of comments from the teachers regarding implementation of the SWH approach. In addition, the conversations that Dr. Hand and this researcher had with the teachers were also recorded and transcribed for further analysis.

In addition to using teacher responses to open-ended questions during the interviews to assess their conceptions of their roles in the classroom, other researchers have also suggested the use of teacher created metaphors as these allow the teacher to reveal meaning through the use of the metaphor that may be too difficult to do through literal language (Carter, 1990).

Several researchers have used teacher created metaphors as a way to assess what the teachers' perceptions of their roles in the classroom are, determine how accurately the teachers perceptions as stated in these metaphors reflect the teachers classroom practice, and monitor changes in teachers' perceptions over time while implementing new pedagogical practices (BouJaoude, 2000; Hand & Treagust, 1997).

In this study, the teachers were asked to describe their roles in the classroom in terms of metaphors in order to provide additional information regarding their beliefs about teaching. Metaphors were provided on three occasions: approximately two months after beginning work with Tom, four months after this and again three months later. In subsequent interviews, the teachers were asked about their metaphors and to describe what they felt accounted for changes, or lack of change, over the course of the study.

Communication between Tom and this researcher

In order to supplement the observational and interview data, several times during the course of the study, Tom and this researcher had approximately one-hour conversations in which he would report on the progress and struggles of the teachers in implementing the SWH approach. In addition, midway into the study Tom began recording brief comments regarding the progress and struggles of the teachers in implementing the SWH approach after many of his visits with the teachers. These conversations and comments were recorded and transcribed and served to provide additional information regarding the teachers implementation of the SWH approach, changes that occurred during the professional development period, and insight into their beliefs about teaching and learning.

In addition, all email communication between Tom and this researcher were maintained and printed. These data provides additional information about the teachers' implementation

of the SWH approach from Tom's perspective and comments they made that were not recorded but may lead to additional understanding of the teachers' beliefs.

Other artifacts

A small number of artifacts, mainly student SWH templates developed by the teachers and completed student work including tests and lab reports written using the SWH template, were collected during the course of this study. These are used to gain a deeper understanding of how the teachers implemented the SWH approach. The collected documents complemented the other data sources and provided information about the participants' experiences that could not be obtained through any other means.

Data Analysis

Videotape

To assist in the analysis of each videotaped lesson, a detailed set of notes was made including transcription of large portions of the students' and teacher's dialogue, the types of activities used, the perceived focus of the lesson, relevant teacher behaviors such as body language, and what the students were doing. Each tape was viewed multiple times analyzing different aspects of the lesson and reanalyzing as new areas of interest developed during analysis.

The primary tool used for analysis of the teachers' pedagogical practice was the Classroom Observation Protocol (hereafter referred to as the COP) (Horizon Research, Inc., 2004) developed by Horizon Research, Inc., as part of the core evaluation of the National Science Foundation's Local Systemic Change program (this can be downloaded at http://www.horizon-research.com/LSC/manual/0506/tab6/cop0506.pdf). The protocol and the items it contains are based on the standards of quality science instruction as outlined in

the *National Science Education Standards* (National Research Council, 1996) and mathematics instruction (National Council of Teachers of Mathematics, 2000).

The ratings section of the COP consists of a capsule description and several categories of items measuring key features of a lesson: design, implementation, content and classroom culture. Responses to the capsule ratings are given on a seven point scale from "Ineffective instruction" to "Exemplary instruction" (see Appendix B). Responses to items in each category are based on a five point scale. Synthesis ratings are given for each category on a five-point scale from "Not at all reflective of best practice in science/mathematics instruction" to "Extremely reflective of best practice in science/mathematics instruction".

In reporting the results of a study of 180 lessons taught by science teachers across the United States, Pasley et al. (2003) created three ranges of quality. Lessons that were given a capsule description rating of 1 or 2 were described as "low in quality" and accounted for 62 percent of the lessons observed. Lessons that received a rating of low 3 and middle 3 were described as being "medium in quality" and accounted for 24 percent of the lessons observed. Lessons that received a high 3, 4, or 5 were described as "high in quality" and accounted for only 13 percent of the lessons observed.

When analyzing the teachers' pedagogical practice using the COP, and in reporting the results, particular attention was given to the four key indicators that Omar (2004), in a study of sixteen teachers as they implemented the SWH, concluded were important in distinguishing teachers who implemented the SWH approach well from those who did not. These key indicators are the degree to which the teacher: a) promoted student to student dialogue to increase the public sharing of knowledge in the class, b) focused on the big ideas

(both in planning and during instruction), c) used effective questioning, and d) created an effective learning environment through effective classroom management.

The Classroom Observation Protocol has been used in several research studies and the internal consistency, content validity, and rater reliability has been established (Horizon Research, Inc., 2000) when used in secondary science classrooms. To establish content validity, multiple reviews of the protocol were conducted by approximately sixty science and mathematics educators during which time items identified as not appropriately measuring the intended objective were revised and submitted for further review until broad agreement on all items was reached. To establish rater reliability, approximately forty-five trained observers were compared to the rating key standard on a common observation of a videotaped lesson. On the seven-point descriptive scale, ninety-two percent rated the lesson within one rating level and fifty-seven percent rated the lesson in exact agreement with the rating standard. Thus, the protocol is considered reliable for trained raters if their ratings fall within one category of the rating key standard. Results of an internal consistency analysis were quite high with Cronbach's alpha ranging from 0.92 to 0.96 for the items in the protocol. These results were taken as sufficient evidence that the instrument is valid and reliable for use in this study.

As with any observation protocol, intercoder agreement is also a fundamental concern. For example, two raters can observe the same lesson and give different ratings based on assumptions that often must be made about the particular lesson being observed. Because this study relied upon a single researcher, intercoder agreement with the instrument was established prior to the coding of the data set. This researcher participated in a training workshop with Dr. Joanne Olson, who has participated in formal training workshops on use

of the COP and has demonstrated high intercoder agreement with the developers of the instrument at Horizons Research, Inc. Videotapes were watched and independently coded until we reached intercoder agreement on each category at 0.85 or higher.

In addition, to further ensure consistency in coding with the data used in this study, three of the fifteen lessons were observed by another graduate student involved in studies of the SWH approach, with agreement to within one point on the seven point capsule description ratings further demonstrating rater reliability. This approach also provided an opportunity to identify discrepancies in the ratings and discussions, leading to refinement in the understandings of what qualifies as a specific capsule rating.

To supplement the Classroom Observation Protocol and provide a description of a teacher's general questioning pattern during each recorded lesson, three five minute segments that are representative of the teachers' use of questioning were analyzed by use of the SATIC coding system (Abraham & Schlitt, 1973)(see Appendix C). This provided a detailed description of the verbal interaction patterns of each teacher in a number of categories including the type of questions asked and the way in which the teacher responds to students' answers. Use of the SATIC coding system allowed for patterns in a teacher's questioning to be identified and examined over time for changes towards patterns that more likely support students' use of inquiry. For example, a teacher may begin with a pattern where they ask a question, the student responds, and, the teacher evaluates the student's response. This same teacher may improve his or her interaction patterns over time to a pattern where several students' responses are elicited from a single question and a student discussion facilitated about the validity of the various responses. Excerpts from the transcripts of the lessons were

used to provide examples of the types of interaction patterns that the teachers are using in a given lesson and how they may have changed over time.

Interviews, metaphors and teacher dialogue

Relevant themes relating to the teacher's experiences, and to their beliefs about teaching and learning, that may have guided their implementation of the SWH approach were identified through the analysis of multiple forms of data collected at various times during this study, including interview transcripts, metaphor responses, email communications, excerpts of classroom dialogue, and teacher dialogue with researchers. These multiple sources of data were analyzed using both open- and focused-coding (Esterberg, 2002). Initially, the data were analyzed using open-coding to develop potential themes. Once it was felt that the relevant themes had been identified, focused-coding was utilized whereby the transcripts were reanalyzed using the themes that had been identified.

In many instances, triangulation of a theme occurred as it was identified in multiple data sources, in the same type of data source but at different times, or both. For example, teachers provided information during multiple interviews that was also supported by observation and comments from Tom, allowing for the development of themes regarding their beliefs about teaching and learning.

Summary

In order to determine the extent to which a group of three teachers in a small rural school district changed their practices in order to more effectively implement the Science Writing Heuristic approach to inquiry instruction while receiving in-class professional development support, and to better understand the role that their beliefs about teaching and learning played in the change process, a qualitative, interpretive, case study research design was employed in

this study. Multiple data sources were used, including videotaped observations of lessons and semi-structured interviews with the teachers, to triangulate conclusions regarding the research questions that framed this study.

CHAPTER 4. RESULTS

Introduction

Using an interpretive qualitative case study approach as described in the methods chapter, this study examined three teachers for changes in their pedagogical practices and beliefs about teaching and learning as they implemented the SWH approach while participating in a professional development program. In addition, this study also attempted to determine possible interactions between the teachers' practice and beliefs that may have influenced the extent to which effective implementation of the SWH approach occurred.

The primary tool used for analysis of the teachers' pedagogical practice was the Classroom Observation Protocol (COP) and is described in chapter three of this study. Briefly, the COP provides ratings consisting of an overall capsule description of the lesson and several categories of items measuring key features of a lesson: design, implementation, content and classroom culture. Responses to the capsule ratings are given on a seven point scale (1, 2, low 3, solid 3, high 3, 4, 5) that ranges from "Ineffective instruction" to "Exemplary instruction" (see Appendix B). Ratings for each category are on a five-point scale where one is "Not at all reflective of best practice in science/mathematics instruction" to five which is "Extremely reflective of best practice in science/mathematics instruction".

The teachers also provided written and oral responses several times during this study to questions relating to changes they believed had occurred in their practice and beliefs about teaching and learning. In addition to providing explicit comments about the teachers' beliefs, these responses were also analyzed for any inferred beliefs that may have affected the teachers' implementation of the SWH approach. Italic font is used to refer to direct quotes from observation, interview and other sources.

In this chapter, the case study results regarding the teachers' pedagogical practices, views on teaching and learning, and possible changes in each, will be presented for each teacher individually. Extensive improvement in their pedagogical practice should lead to increases in the capsule description ratings given for each lesson; thus, these ratings will first be presented for each teacher to examine if any teacher underwent extensive change in their practice. Acknowledging that a teacher may have made change in only certain areas, or small improvements over all areas, yet not enough to change the general pattern of capsule ratings for individual lessons, the individual rating category results will also be presented and discussed for each teacher. The reliability and validity of the results reported will be strengthened through triangulation of many sources of data, including the results of analysis using the COP, vignettes from lessons representative of their practice, interview quotations, documents provided by the teachers, and information provided by Tom.

In this chapter the teachers' actions during this study are often referred to as having occurred while "implementing the SWH approach". Use of this and similar phrases is not meant to suggest that the use of the SWH approach alone was responsible for changes that occurred during this study, or to neglect the important role and potential impact of the professional development support that Tom provided for the teachers. Rather, use of such phrases shortens this chapter significantly and is considerably easier to read than "implementing the SWH approach while being provided professional development support by an experienced, retired teacher".

Fred

At the time of this study, Fred had several years of teaching experience at the middle school level and was responsible for both sixth and seventh grade science courses. He

demonstrated the most ineffective pedagogical practices of the three teachers involved in this study and had the most room for improvement. Yet he was unable to sustain any changes in his pedagogical practice during the course of this study. In addition, his beliefs about teaching and learning appeared to contribute to the struggles that he encountered implementing the SWH approach.

Practice

Fred stated that a major reason for entering into this project to implement the SWH approach was that he wished to place less reliance on use of the textbook. While he was able to accomplish this for several months, by the end of the year students were observed reading from the textbook during class. As reflected in the capsule description ratings of Fred's lessons (see Table 1) and the rating for each of the individual categories, overall, there were no long-term significant changes in his pedagogical practice detected during the course of this study.

Table 1. Fred's ratings

Lesson	1	2	3	4	5
Capsule description	2	low 3	1	1	1
Design	2	5	1	1	1
Implementation	2	3	1	1	2
Content	2	3	3	2	2
Classroom culture	2	2	1	2	2

The significantly higher capsule description and individual category ratings would seem to indicate that Fred made improvement when first implementing the SWH approach in the

second observed lesson. However, he struggled to maintain these changes and subsequent observations were ranked as level one – ineffective instruction, indicating that any improvements seen in the second lesson were likely not indicative of fundamental change in Fred's pedagogical practice. Rather, the improved ratings in lesson two are likely attributed to the significant role Tom played in assisting Fred in this lesson. Tom both helped develop this particular lesson and modeled proper implementation prior to Fred being videotaped.

Finally, it should be noted that whereas the other two teachers participating in this study used the SWH approach for much of the year, Fred used it for only one unit. In addition, unlike the other teachers who reported spending additional time planning instruction as a result of using the SWH approach, Fred did not. This suggests that Fred may not have been fully committed to devoting the time and effort needed to improve his practice.

Design

While there were no long-term changes in Fred's ability to effectively design lessons, he was able to achieve one of his goals, that of a reduced reliance on use of the textbook, albeit for only a few months. He continually expressed a goal that the textbook not be the primary source for students to learn from in class, stating that students would "*hopefully think of science as not just the science book and doing questions on a certain page*." Fred reported that there had been an impact on his use of the textbook during the early stages of his implementation of the SWH approach, stating that "*I always said I want to get away from the book, and yet it never really happened. Then as this came on, it enabled me to pull away from the book even more, use it as a guideline, but it's just a tool. I think that has helped a lot*." He noted that much of this involved change in himself, as "*We have been staying out of*

that textbook a lot and part of it is convincing myself that I don't have to use that with them, they don't need it and I love that part because I want them to pull in outside experiences."

In explaining what he felt was wrong with using the text as a primary means of learning, Fred stated that "*I think it's kind of monotonous sometimes. I think that it makes it harder to tie everything else in to place*." Fred stated on several occasions that he viewed the text as "*just a tool*" and that "*I just want them to see it as a tool and not the class, you know. It's an important part of it, but I don't want it to be the all encompassing part of the class."*

However, Fred did not want to completely abandon the text, stating that "*I still want to use it as a guide to facilitate me and them but I don't want them to have to be just in the book all the time*." As the year progressed it became more difficult for Fred to develop lessons that did not rely on the textbook and during the last lesson observed the textbook was the primary source of student learning. The students provided answers to homework questions from the text and read passages from the book followed by teacher led discussions of the vocabulary terms. Fred recognized that the lesson was not very effective, stating that "*We're in the book, I'm behind a desk, it's just a monotonous classroom that you don't want to have*." He also realized that he was once again relying on the textbook, stating "*I'm right knee deep in it again, I was out of it for while but now I'm back*."

Fred's reliance on the textbook was also reported by Tom who, in reporting on the difficulties Fred had implementing the SWH approach during the year, expressed the belief that "*He just can't let go of that textbook because he seems to think that there's a tremendous amount of vocabulary etc that these kids need to know and in the process then reverts back to where he feels kind of comfortable*." While Fred's focus on students' understanding vocabulary words and facts will be discussed under the category of content, it should be

noted that this appears to have contributed to his reliance on the textbook in designing lessons.

Fred also appeared to struggle with selecting appropriate activities to engage students in the construction of scientific knowledge. Fred did appear to hold a lofty goal regarding students and what he wanted them to be able to do as he stated "*I'm bound and determined to get them thinking like a scientist instead of just answering science questions in a book, you know what I mean, with the scientific method*." While Fred's use of 'the scientific method' may not have reflected an understanding of scientific inquiry as proposed in the *NSES* (National Research Council, 1996), this statement indicates a desire for students to do many of the things scientists do – including 'investigations'.

However, except for the activities observed in lesson two, activities observed in other lessons, or described by Fred, rarely provided students the opportunity to engage in investigation of meaningful questions regarding natural phenomena. In addition, despite the school's alternating block schedule, with longer class sessions providing additional time to conduct hands-on investigations, the students were typically involved in completing verification or demonstration exercises, including making posters portraying ideas they have studied, building models of cells, developing presentations on evolution, and finding answers to questions using the internet or other sources. While most of these activities could be used effectively within an inquiry setting, what is troubling in Fred's case is that there were no hands-on investigations occurring.

Fred also placed inappropriate emphasis on students having fun in class as he repeatedly stated how much fun students had when discussing the activities done during the year. For example, he noted that he had chosen to do one activity specifically because students the

previous year had liked it so much, explaining that "*I know a lot of the 8th graders were talking about how much fun that was so I made sure I wanted to get that into the classroom and they had fun with it*." That a successful activity is one where students have fun also appeared to be more important than effective management of class time. Fred acknowledged that while the evolution project he used instead of the second unit with the SWH approach had taken a long time, he felt it was worth it as "*Everybody had a lot of fun with it, so it was a good thing to do*." This belief in the importance of student fun during activities is best summed up in the following passage:

> If I hear of a student that claims that, for instance, science is his most fun class, that to me in a lot of cases means more than test scores. If they're finding it fun, not that they just run around in here crazy, but if they start to like it, then they'll spend more time with it and you know eventually come up with more than the person who just goes through the motions.

Yet while Fred emphasized how much fun students had with many of the activities used during the year, this was not mentioned when discussing the use of the SWH student template. Rather he noted how 'tough' it was for the students to complete and that "*They seem to be lost in it quite a bit, the approach that we took.*" That the students were not having fun with the SWH, an aspect of learning that seems crucial to Fred, may have attributed to his not using the SWH approach for additional units.

In addition to using predominantly 'fun' activities that did not involve students in inquiry, and may not result in significant increases in students understanding of the concepts being studied, Fred also demonstrated poor management of the time allotted to complete activities. For example, in the unit prior to using the SWH approach, Fred had the students build models of the cell. While it is a common practice to have students build models of the cell, in most cases these projects are completed at home. However, Fred had the students build their

models in class and allowed eight days for this to be accomplished. Fred recognized that this was too much time as he later admitted that the cell project was "*one of those things that kind of took a little more time than I was planning on.*"

Despite Fred's awareness of this problem, his time management skills do not appear to have improved as eight days were allotted for the evolution project that Fred chose to have students do rather than an additional unit using the SWH approach. This project involved research and development of presentations on evolution in cooperation with a language arts teacher that, based on Fred's description, appears to have focused on the presentation of information rather than development of understanding.

In addition to this three week project, Fred also reported having students spend two class periods building models of viruses during the evolution unit. Based solely on these numbers, the students spent eighteen of ninety class sessions, or twenty percent, of their instructional time doing activities of little apparent educational value.

Finally, Fred appeared to not understand that the integration of language and science is a crucial part of the SWH approach. In explaining the benefits of having the students involved in the collaborative project, he stated that "*So, tying it into another curriculum and taking science and putting it into the language arts classroom and vice versa I think kinda gave them a better overall look at it hopefully*."

Implementation

Fred struggled to improve his implementation of lessons despite the professional development assistance that he received from Tom (see Table 1). Overall, four of the five lessons were rated either one or two, indicating that the implementation of the lesson was not likely to assist students in developing their understanding of the science concepts.

Fred's overall verbal interaction pattern was characterized by asking closed-ended questions requiring yes / no or short answer responses, providing less than adequate wait times due to repeating or praising students' responses, and accepting and praising of responses rather than asking for elaboration. His non-verbal behaviors were best characterized as neutral as no physical actions were exhibited that appeared to inhibit or encourage student participation. The following excerpt of dialogue between Fred and a student (Stan) reflect Fred's poor questioning skills:

The student ("Stan") begins by reading the question that he has.

Stan: *Why are animals different sizes*?

Fred: *Ok*.

Stan: *I already know they live in different places*.

Fred: *Good*.

Stan: *The text says because of their environment*.

Fred: *Good*.

Stan: *And another resource says because they evolved over hundreds of years*.

Fred: *Good*!

Stan: *And because they are camouflaged* (can't make out last several words)

Fred: *Good*.

Stan: *And because of their surroundings, like* (can't make out one word)

Fred: *Ok, at the end, you summed it up that they're their size because of their surroundings. Right?* (The student nods his head yes). *Very good Stan, that was great*! (other students clap)

In this interaction, Fred accepted the student's answers and did not ask for clarification or elaboration of any responses; thus he was unable to determine if this student had actually learned anything in relation to the question. Rather, what all the students may have learned was that it does not require much effort to develop acceptable answers to their questions.

Fred did exhibit improved verbal interaction patterns during the second lesson; especially while leading the students in a group concept mapping task. When the students struggled with developing linking terms and phrases, Fred used wait times of at least five seconds while waiting for responses. In addition, several times he asked students to provide more detail about how a linking phrase connected the term they provided to the big idea of heredity.

While this improvement in Fred's verbal interaction pattern indicates that the modeling that Tom did prior to this and other lessons may have been helpful, there were no indications of overall progress. There was very little use of questioning during the third lesson and his verbal interaction patterns were characterized by the use of low level questions requiring yes/no and short answer responses during the last two lessons.

Fred's classroom management style and strategies may have also contributed to the difficulties he experienced in implementing the SWH approach. In general, Fred did not appear to actively manage the classroom. While the students overall were not disruptive, it appeared that this may have had less to do with actions taken by Fred, but rather that he is a large, male, former Army Ranger, who by virtue of size may demand respect. In addition, Fred's belief that class should be fun appeared to allow for more off-topic student talk and joking than might be observed in other classes. While a passive classroom management style resulting in a jovial environment does not necessarily lead to poor instruction, this lack of control may have led to some of Fred's difficulties in promoting student dialogue that will be reported later.

Only during the last observation, when the students answered questions from the book, read part of the chapter and discussed the vocabulary terms, did the students' behavior cause

Fred to actively attempt to manage their behavior. Fred stated that the class had not behaved well that day and would be writing apology letters to Tom.

Content

During the year Fred attempted to engage the students in studying many concepts, including those related to the cell, heredity, evolution and ecology; all of which are worthwhile concepts for the students to learn and can be done in a developmentally appropriate manner for middle school students. However, Fred struggled throughout the year to develop and implement lessons that would assist students in developing an understanding of the concepts (see Table 1).

While Fred often stated goals that reflected a desire for the students to develop an understanding of these fundamental concepts, he tended to focus on facts and vocabulary when designing and implementing lessons. For example, in discussing what he wanted the students to understand about the cell, he stated what appeared to be an appropriate learning goal for middle school students: "*I wanted them to see that a cell is like a little organism in itself that carries on life's processes. And its created of organelles which are little organs so that they could see even on a cellular level how life is working the same as a whole person*."

Yet in designing and implementing this instructional goal, Fred chose to have the students construct "*big and elaborate models*"; for example, one group of students made their model from a refrigerator box. In addition to size and detail, the other key requirement was that the models had to include the correct information; that is, all of the organelles had to be present and labeled. It is unlikely that building a large model of the cell and labeling the organelles assisted the students in achieving the learning goal that Fred had stated. As the instrument that he used to assess understanding was a quiz requiring the students to label the

parts of the cell, it was not possible to determine if the goal was met. However, Fred did report that many of the students did not do well on the quiz and stated "*that was kinda disappointing, cause I was expecting everybody to at least know the parts from making it*."

This focus on vocabulary terms and facts was also reported by Tom on several occasions. For example, Tom stated a concern that one of Fred's difficulties in implementing the SWH approach was that "*he was a classic case of when things got a little tight he retreated to his old teaching mode. [It is] usually "yeh, but I want to be sure they have the facts.*" Tom also reported that Fred would have the students play games to make sure they knew the facts.

Fred's belief that students must know the facts led him to be concerned about implementing the SWH approach as the use of the textbook is not emphasized. Fred reported when first using the SWH approach that "*I worry about missing information for them that they need to be picking up*."

The emphasis that Fred gave to students knowing vocabulary terms and facts, may arise from his belief that students need to learn this information now so that it will be easier to remember the next time they need it. In the following passage, Fred discussed how the students memorizing the cell parts and the functions of each will benefit them in the future:

> Because there have been several things throughout this year that have built off that cell being that functional unit. If they have to pick it up that one time in here and say, say they have to memorize all those parts and then regurgitate them on a test, well they've learned it at one point. Know as soon as they hand that test in and walk out my door and go home for the weekend and come back, they have probably dumped some of that and that's ok. They knew it at one time, and now for them to pick it up again is going to be a lot easier. It's like a foreign language if you don't use it you start to forget it but you can start picking it up again if you practice, so it's a lot easier the next time. Like, say, they don't see that until high school biology again, well, they know that there's organelles in there and they remember that each one had a reason to be there. Well, now, they are going to have to go back and look at it again and

> it'll come a lot quicker and they can focus on what they are learning at that time then. Hopefully. That's the way that I look at it anyway.

Fred's difficulty with designing and implementing lessons so that students can develop an understanding of the concepts was also evident during another observation. He had stated a goal that the students should understand how traits are chosen at random and the difference between genotype and phenotype. Students were observed simply drawing and coloring their 'baby' based on the flips of a coin. Fred did not ask students questions or engage them in discussion designed to relate the activity to the big idea of the unit. Thus, the students were not intellectually engaged in learning these concepts, and very likely did not understand them as seen in the following conversation between Tom and a student as he taped the class:

Tom: *So how did you decide your traits*?
Student: *We flipped a penny*.
Tom: *So you did it random by flipping a coin*?
Student: *Yeah, just random*.
Tom: *Ok, is that how it usually works, just by random chance*?
Student: *Probab…, I don't know*.

The student did not finish speaking the word probably and was laughing as she said "*I don't know*." This student seemed to realize that she did not understand the concepts. While the lack of effective instruction prior to this observation possibly accounts for much of the student's lack of understanding, this lesson did not result in the diagnosis of this lack of understanding nor provide adequate opportunities to move the students' understanding of inquiry forward.

As Fred only had the students use the SWH template to complete one investigation, and was not observed having the students use the claims and evidence terminology in any other lessons, it is assumed that he did not implement this important aspect of the SWH approach.

Classroom Culture

Fred also struggled to develop a classroom culture that promoted scientific inquiry. For example, one of the key indicators of an effective inquiry classroom culture - that of intellectual rigor, constructive criticism and the challenging of ideas - was rarely observed. As reported previously, students' responses were typically accepted without challenge; only when a known response was desired, often a vocabulary term or definition, did Fred challenge the students.

Fred's belief in students having fun was evident in the classroom culture. Joking and laughing often took place during formal instruction and while completing activities. This often appeared to interfere with learning as students would give responses that they knew would cause laughter in the class.

Fred was also unable to implement student dialogue effectively. He would often allow students to call out responses while others were speaking, thus creating difficult conditions in which to develop classroom discussions. An additional constraint on his promoting student dialogue was that, as reported previously, he often repeated student responses rather than allowing other students the opportunity to speak.

This difficulty was also evident in lesson two, which Tom helped plan and also modeled for Fred. While there was an increase in intellectual rigor and less emphasis on having fun, the male students dominated discussion during the concept mapping portion of the lesson. This was noted by many of the students during class, yet Fred did not take actions to engage the female students and continued to allow the males to dominate the discussion. Fred mentioned this problem to Tom when reflecting on the lesson after class and expressed that he wished it had been handled differently.

Based on the difficulties that Fred had with using the SWH approach in the first unit, he began to doubt that the students were developmentally capable of completing the process, stating that "*I'm almost to the point where I'm thinking at middle school level, they're not able to function that way, … it's not the way their brain's working at this point in life I think in a lot of ways.*" Fred appears to have been stating a common teacher belief that acts as a barrier to implementing inquiry approaches, that the students are not capable regardless of what the teacher does.

Beliefs about teaching and learning

Fred's beliefs about teaching and learning did not appear to change during the course of this study; a conclusion that Fred reported also. However, Fred's beliefs about teaching and learning provide insight into understanding why he was unable to effectively promote the use of inquiry in the classroom in general, and specifically, through use of the SWH approach.

Teaching

Fred's initial written response to the task of developing a metaphor to describe his role as a teacher was "*That's easy. I am like the wind, I stand up there and talk and it goes in one ear and out the other*." This response provided little insight into his beliefs, but it did reflect the light-hearted, 'let's have fun' nature that Fred demonstrated in classes and was detected in both interviews.

However, in the definition of teaching Fred provided at the same time, that a teacher is "*A magician. An example setter and a facilitator,*" he expressed a belief that his role as a teacher is to be a facilitator. Approximately three months later he again equated teaching with facilitating when he defined teaching as "*the facilitating of new understandings, theories, and experiences.*"

The metaphor of teacher as facilitator was also used when Fred provided a second, and more significant response to the metaphor task, stating that learning was "*like water and I was like the raft or whatever that they were on to get from point a to point b."* Explaining what his role as the raft would be, he noted "*That would just put me as the facilitator there to help them get from one point to another and the waterway being the learning process*."

In discussing this metaphor further three months later, Fred stated that "*Well the water would be like the learning process. As they go, knowledge and these things that they pick up on the way and you're just kinda directing it, you could be the raft or whatever that they are on as they go. You could be the bank keeping them in check as the water flows through a riverbed too, I don't know*" (BLi2.) While he does not specifically refer to his role as a facilitator, phrases such as "directing it" and "keeping them in check" seem analogous to facilitation.

When asked to discuss how he would facilitate students understanding, Fred commented "*Well, I guess when I think about the brainstorming,… I'm giving them a focal point to look at while they're coming up with things that they know already in the brainstorming. So if I can, they've got to have some form of direction or they'd be talking about skateboarding all day. I kind a see that as the facilitating end of it.*" In this statement, Fred makes little reference to the many teacher practices that are required in order to effectively implement inquiry, such as asking higher-order questions to probe for student understanding, designing activities that create conceptual conflict in students, and nurturing classroom discussion about students investigative results and how they can be best explained. Yet in his concluding remarks, he expresses a satisfaction with this limited role that he describes,

stating *"If I can convince them in anyway that either they figured it out or they understand this now, then I'm doing what I need to be doing.*"

Thus it appears that Fred's belief that his role as teacher is to be a facilitator with a limited role for him to play, may have played a significant part in the difficulties he had with implementing the SWH approach. How his beliefs about learning also contributed to his struggles will be discussed next.

Learning

Fred provided two definitions of learning during the year, neither of which conveyed much insight into his beliefs. Learning was initially defined as "*Understanding concepts of bigger pictures than the information they are getting inside of the school."* Three months later Fred wrote that "*Learning is the understanding of new things and their relationship to our world based on prior knowledge and past and present experiences."*

While these definitions provided little insight into Fred's beliefs about learning, additional comments did. In explaining what his initial definition meant, Fred stated that "*They can learn something in the classroom and walk out the door and not have any idea what it was or they can walk out of the school and see it elsewhere in their lives."* In this statement he appeared to express a belief that a crucial outcome of learning is the ability of students to use the knowledge learned inside the science classroom in their lives outside. This belief was stated more clearly when Fred discussed the second definition, stating that "*Understanding new concepts or old concepts. I don't think it's so much making discoveries of things that nobody knew were around, it's understanding how to apply stuff to daily life.*"

Fred also appeared to believe that making links to events outside the class was just a goal of learning but also important part in learning, stating "*If they can relate it to something else,*

I think that it'll click a lot better for them. That's why in the spring and the fall I try to get outside as much as I can and try and let that mind expand a little bit." While assisting students in linking classroom knowledge with outside events may improve their understanding, Fred's belief in how this should occur was troubling.

In discussing how he would help students make connection between the class and outside, Fred stated that his job as a teacher was to "*try to give them as many different ways to look at it as possible is that they can tie it into something outside of the classroom*." In this passage he appeared to hold a belief that his role is to give the students different ways that they could choose to make a link with the outside world. This belief was also evident when he was discussed ways to assist students in linking past experiences with new experience, stating that he would "*make them see that connection. Show them the new thing, whatever it is, the new topic, show them something that it is going to make it important to them, and then hopefully something that will allow them to link it to something that they already know so that they can see how it falls into place*."

These statements about learning and his role appeared to reflect a belief in a type of 'knowledge-transfer' in that Fred's task was to 'show them something' that they can use to make the links. In addition, he appears to believe that once he has shown the students 'something', it is now up to the students to make connections and he plays no further role. These beliefs are not congruent with the actions that should be taken in a classroom that emphasizes inquiry and student construction of knowledge. They also help to explain the difficulties that Fred encountered in implementing the SWH approach.

Fred's belief that it is crucial for students to apply all they have learned in the class to their lives may come in part from his understanding of what science is. In discussing why

students need to learn science, he expressed a belief that science deals with everything, as seen in the following passage:

> So that they understand the world around them, … everything deals with science, from the hamburger that they ate for dinner to why they need sleep at night to their viruses and their antibiotics, all that is tied into there. To care for the planet and the ozone layer, we've been discussing all this stuff. And that, I guess, just having the knowledge of how their world's working around them is the biggest thing. Because it's all, at this point in their life, that's going to lead in to the other things; if they are going to go and be the great scientists and come up with the cures for things.

In this passage, Fred expressed a belief that he sees the goal of students gaining knowledge of science to prepare them to become scientists and develop cures; which can be viewed as an admirable goal. Yet, as reported previously, Fred also expressed a belief that student learning in science was not about "*making discoveries of things that nobody knew were around.*" While this phrase may not provide a philosophically sound definition of science, it is analogous to common misconceptions of science. If Fred does not believe that investigation plays a crucial role in school science, then it would be very unlikely that he could easily incorporate inquiry into his pedagogical practice. This provides valuable insight into why he struggled to implement inquiry in the classroom. On one hand he wants students to be able to 'make cures' as adults, but he does not see it as his task to engage them in the sort of practices that would enable them to make discoveries as adults.

Summary

Despite having the most ineffective pedagogical practices of the teachers involved in this study, and thus requiring the most improvement, Fred was unable to make any lasting change. He experienced difficulties in designing and implementing lessons that would create a classroom culture in which students could develop a deeper understanding of fundamental

science concepts appropriate for middle school students. The activities that students participated in did not engage them in the process of inquiry, but rather stressed the presentation of information and memorization of vocabulary terms. In addition, Fred demonstrated poor time management as these activities accounted for approximately twenty percent of instructional time. Finally, Fred's questioning practices did not support student generation of knowledge as recall of information was stressed.

Fred's beliefs about teaching and learning appear to have played a major role in the difficulties that he experienced implementing the SWH approach. His belief that the most important factor in learning was the extent to which students had fun was reflected in the activities that he chose to use and the atmosphere that was created in the classroom; neither of which promoted inquiry. Although Fred expressed an admirable goal that students should use the knowledge they have gained in situations outside the classroom, the lessons he developed reflected his belief that students should learn the facts in preparation for future classes. Fred also expressed a belief that his role as teacher was to facilitate students learning, yet his actions and statements suggest that a belief in teaching and learning as knowledge-transfer more accurately describes his beliefs.

Sofia

Although Sofia was only completing her first full year of teaching during this study, she began with effective pedagogical practices as reflected by the capsule description rating of high three for the first lesson observed. Sofia did not believe that she was being asked to do anything differently than the methods that were stressed in her college educational preparation program. In the following passage she discussed what she felt was her excellent

preparation for teaching science and how the SWH approach and another inquiry-based professional development program she had participated in were an extensions of this:

> The lady that was the head of all that [science education] was a very strong constructivist and so she was constantly pushing hands on, keep the kids involved and responsible for learning. So I think that a lot of that ties right into the [previous professional development program] and SWH and things that I was stressed and taught to do in college really. So I don't know that it has really changed anything, it's just kind of reemphasizing and adding more tools and ideas.

Practice

During the course of this study Sofia changed the type of activities that she utilized, beginning the year using traditional textbook laboratories yet modifying existing activities or designing her own as she used the SWH approach. In addition, Sofia reported changes in the reliance on textbook use in class, an increase in the use of discussion as an instructional strategy, and in her understanding and use of questioning. These changes will be discussed in the relevant sections below.

It is also interesting to note that while Fred demonstrated improvement upon first using the SWH approach in his lesson two, Sofia received the lowest ratings in lessons two and three when doing so (see Table 2). There are several possible explanations which may account for this. Sofia began with relatively effective practice and may have experienced difficulty in implementing a new approach thus resulting in lower ratings. In addition the focus of these two lessons was the abstract concept of atoms and elements whereas the other lessons observed dealt with physics concepts, including forces and motion. The physics concepts may both be easier for an inexperienced teacher to develop inquiry activities for and more developmentally appropriate for the students, thus creating less difficulty to implement and increasing the likelihood of developing higher quality lessons.

Table 2. Sofia's ratings

Lesson	1	2	3	4	5
Capsule description	high 3	low 3	2	solid 3	4
Design	3	3	2	4	4
Implementation	4	3	3	3	4
Content	4	3	2	3	4
Classroom culture	4	4	3	4	4

Design

Prior to implementing the SWH approach, Sofia was observed using 'cookbook' lab activities that provided directions for the students, data tables to be completed, and questions to be answered. While the students did work cooperatively during the laboratory activities, they did not share their results with each other, rather answers to the lab questions were discussed during a whole class session.

As Sofia began to implement the SWH approach, along with Tom's assistance, she developed activities rather than use those in the textbook. However, as she had chosen the concepts of atoms and elements for this unit, not surprisingly, she experienced difficulty in designing activities, even with Tom's assistance. Together they developed an activity involving the students in generating questions relating to the iron content in cereal. While some students did decide to test for varying amounts of iron in different cereals, most were satisfied with simply seeing the iron particles on the magnets. In addition, as the students had previously discussed that iron was in food, including cereal, it seems that in the end this activity more closely resembled a verification exercise than an inquiry investigation.

In the other activity for this unit, the students generated questions and did research in the library and on the internet in order to develop answers. Students used the SWH template to outline the steps taken to generate their claims and provide the evidence that had been gathered. This does not seem consistent with the theoretical foundation of the SWH approach as it did not involve investigation of natural phenomena nor sharing of ideas as the work was done individually. Rather, this exercise seems to have been Sofia's attempt to utilize the SWH template and follow the approach's philosophy of having students develop and find answers to their own questions. One has to wonder if she would have done this activity if not for trying to implement the SWH. However, it should be noted that Sofia was aware of the limitations of this exercise as she commented that:

> I'd like to see it again with another experiment where they are asking questions that they are going to test because with the research, like how did you find your answer, how did you test it or whatever. They had to just write down … "I looked in such and such book and I went to this website", so that wasn't, I don't know, I don't feel like that is a lot of hands on science.

The difficulties that Sofia experienced in implementing the SWH approach during this first unit might have caused her to abandon the SWH approach. Yet she understood that much of the difficulty that she experienced was due to the abstract nature of the concepts that were chosen for this first unit, stating that "*With the periodic table and the atoms and things that you can't see, we had Bill, he would try and brainstorm some things too and he had some neat ideas but we had a hard time coming up with activities that they could do and hands-on kinds of stuff.*"

Sofia was also aware that her choice of concepts for the second unit, force and motion, not only provided more opportunity for the students to be engaged in hands-on investigation, but that less abstract concepts would also assist the students in learning to work within the

SWH approach, stating that "*I'm looking forward to a unit where they can actually see and do and not have to think about things that nobody has ever seen. So just to see how they do it, they're familiar with the SWH, see how they can do that with things they can actually touch. I think it should go well*."

Rather than revert to using the materials that accompany the text, Sofia searched the internet for labs and activities the students could do during the next unit on forces and motion. She decided to modify five Physics Olympics activities, including rocket balloons and toothpick bridges, so that the students had more of a role in developing the plan to complete the specified task. For each activity, the students had to develop a design for their device and discuss how motion, force and other related physics concepts they were studying applied to the particular device they constructed. For example, in the egg drop activity, the students had to use the concepts of force, motion, gravity, and acceleration to explain how their device worked. After conducting an activity, the students would then complete the SWH student template based on their experience designing and testing the device. The initial activities were completed after a minimum of formal study of the concepts, and thus the students may have been using the terms and concepts without much understanding. However, in the latter activities, the students appeared to have developed a deeper understanding of the concepts and were now applying them in new situations.

Even with the modifications that Sofia made, these activities may not accurately reflect the true nature of inquiry. These activities appear to have been more about trial and error in designing an effective device rather than inquiry into the scientific phenomena that explain how the device operates. For example, the goal of one activity was to design a light, yet strong apparatus to protect an egg when dropped. The students did develop a variety of

different devices based on their understanding of forces and motion at the time. Yet the activity did not appear to involve investigation of the underlying scientific concepts. However, students were required to explain how the concepts they were studying applied to the device both in writing up their activities, and through questioning by Sofia during the activities. Thus it does appear that conceptual development was stressed.

Regardless of the extent to which the Physics Olympics activities Sofia chose to use should be considered consistent with inquiry, having chosen to use these activities seems to have had an unexpected benefit. Sofia now spent less time developing activities for the students to do, and was able to focus her planning efforts on dealing with the day to day challenge of what to do with the new questions that the students were interested in. In the following passage she discusses how using the SWH approach had caused her to begin trying to anticipate student questions, stating "*It also helps me anticipate, I try to think 'What are their questions going to be? Am I going to have supplies for them to be able to test that, what are their questions going to be about.*"'

Yet she was also aware that as a beginning teacher, this was a difficult task, stating "*that is kinda hard for me because this is only my well, I haven't even been through some of the material once yet, so it is my first time through so anticipating their questions is kind of hard*." That she was aware of this difficulty is important, because as a teacher who did not understand that improvement may take time and additional experience, might become frustrated and abandon use of the SWH approach.

Sofia reported that implementing the SWH approach during the second unit was much less difficult. She attributed much of this to the concepts being easier for students to test stating that "*I think that these [concepts] are easier to experiment with. They're things that*

they can actually do whereas, with the atom it's so much more abstract. I think they can't see, it's harder to experiment and test those things."

In addition to changing the type of laboratory activities being used, Sofia reported that there has been a change in how she designs the units, stating that "*I would say that it has changed the overall setup of my class … because I don't open the book the first day of the chapter and say 'OK we're reading section one and here's the vocabulary you need to know'… We don't rely on the book as much.*" Reflecting her perception that she was using the textbook less, she also noted that by using the SWH approach "*It makes me look away from the book more and look for some of those things that will keep them like hands on and keep them thinking*."

Supporting this contention, the use of the textbook was not observed in any lessons. However, Sofia still used the textbook in designing and carrying out lessons. For example, the exam for the first unit contained several pages of pre-formatted questions that accompany the textbook, in addition to several other essay type questions she included. Sofia also reported that prior to each Physics Olympics activity there were approximately fifteen to thirty minutes of formal instruction that involved use of the textbook.

Implementation

Although there were no major changes observed in the implementation of Sofia's lessons during the course of this study (see Table 2), it should be noted that all ratings were either three or four, indicating that implementation of these lessons was of moderate quality or better. In addition, the two lowest rated lessons occurred when Sofia was just beginning to use the SWH approach, a time when a teacher might be expected to encounter difficulties, and thus receive lower ratings.

In contrast, the ratings were highest for implementation on the first and final lessons observed. These lessons featured extensive discussion of the concepts being studied and demonstrated Sofia's ability to monitor the students understanding and make appropriate instructional changes. For example, in lesson one the students were having difficulty in understanding how buoyancy and Archimedes Principle were related to the boats they had constructed. Sofia appeared to have realized that the students did not yet understand the relationships as she stated that they would move onto another activity which might help them better understand Archimedes Principle rather than spending additional time attempting to have students provide textbook responses.

Sofia's ability to monitor and effectively manage the classroom was also evident in the final lesson when students were having difficulty maintaining appropriate behavior after spending much of class answering and discussing the questions. Rather than force the students to continue with the discussion under the threat of punishment, Sofia decided to leave discussion of the last two questions until the next class and moved the lesson onto the next Physics Olympics activity.

There were also no significant changes observed in Sofia's overall questioning practices during the study. She exhibited many effective questioning practices from the beginning of the study, including asking thought provoking short answer and extended answer questions, the use of adequate Wait Times I and II, asking students to elaborate or clarify their responses, and having students provide their thoughts about other students comments. Her nonverbal behaviors were best characterized as neutral in that she did not exhibit physical actions that seemed to inhibit or encourage student participation.

However, there was room for improvement in Sofia's questioning practices as she did ask poorly phrased questions such that a simple yes/no or short answer response was required. Yet, in many of these cases she followed the student's response with a question designed to elicit elaboration on their response. In addition, in responding to students' answers, and perhaps reflecting her eagerness to probe for understanding, she would ask "*Why?"* so quickly as to provide no wait time II. While she did repeat students' answers, this response was often spoken in a tone that suggested she was questioning the students' response.

Sofia reported actively reflecting on her questioning practices throughout the study. For example, she often brought up the topic of questioning when discussing ways in which she could improve her implementation of the SWH approach and actively reflected on the progress that she was making. Sofia expressed that she was experiencing difficulty maintaining effective questioning throughout the school day and believed that she needed to monitor her questioning practices. In a later discussion she noted that "*sometimes maybe I don't probe or question enough to really pull out everything that they know, so I need to work better at not just being ok with that surface knowledge*." This reflection also extended to the articles which the teachers had been asked to read. For example, she reported that while reading the article about questioning she was "*assessing where I am at, and highlighting some of the things that you know, making sure that you are not giving them the answers and that you are probing for questions*."

In addition to actively reflecting on her questioning practices, Sofia also reported that she began to anticipate students' questions during the second unit in which the SWH approach was used. In the following passage she describes this change in her practice:

> I found myself spending a lot more time outside of class thinking about 'What are the questions that I could ask them?' or 'What are the questions that they might have?' so I can have a response, something that can redirect them. And then in class as well, trying to, trying really hard at it. And I know I'm not great at it and I still do give them answers from time to time, but really trying to make them find the answer rather than me just giving them the answer.

As suggested previously, Sofia's choice to use the Physics Olympics appears to have reduced the amount of time she spent developing activities thus allowing more time to think about interactions with students. Therefore, while the use of these particular activities might be viewed as not promoting inquiry, Sofia appeared to make significant progress in a very crucial area of pedagogical practice as a result.

Content

During the year Sophia engaged students in studying many physical science concepts. Not surprisingly, Sofia appeared to have less difficulty with the units in which physics concepts were studied compared to the unit dealing with atoms and elements. For example, prior to implementing the SWH approach, Sofia was observed focusing on the big idea 'Properties of Fluids', including understanding the role that shape plays in creating buoyancy which causes boats to float. For the second unit with the SWH approach, which occurred for most of the second semester, the concepts studied related to the big idea of 'Forces and Motion', including gravity and weight, friction and air resistance, and Newton's Laws of motion. Based on the lessons observed and discussion with Sofia, she appeared to have focused on developing an understanding of the concepts rather than memorization of vocabulary and ability to perform mathematical calculations. The level of detail observed indicated that the big ideas studied in the units that focused on physics concepts would be

both developmentally appropriate for students of this age and are worthwhile concepts to learn.

However, for the first unit in which the SWH approach was to be used, Sofia chose the more abstract, chemistry-based big idea of 'Atoms and Elements'. Based on the discussions observed in lesson two, some of the concepts studied were appropriate, including the periodicity of elements and that elements combine to form compounds. However, Sofia also wanted students to describe atomic number and atomic mass, indicating that instruction has occurred involving atomic structure - areas that are more suited for high school students rather than eighth grade students.

Sofia experienced the most difficulty focusing on fundamental concepts relating to the big idea during the third lesson observed (see Table 2), in which the students were finding answers to their own questions. In this SWH activity, the students were seeking answers to two questions: "How long did the periodic table take to make?" and "Why are there only two liquid elements?." While these may have personal meaning to the students, neither question would appear likely to help students develop a deeper understanding of elements. Perhaps Sofia could have worked with the students to refine the questions so that the answers would increase their understanding. For example the question, "How was the periodic table developed?" might lead students to appreciate the fundamental structure of the atom and how small differences lead to different elements. Indeed, Sofia did report that several students developed new questions after having difficulty answering their initial choice.

While this activity could represent difficulties with content on Sofia's part, it should be pointed out that as previously mentioned, it is possible that this lesson was selected to have an activity conducted with the SWH template, and may not have been used otherwise.

Determining the extent that Sofia was able to engage students in developing and supporting claims based upon evidence derived from their experimental data was difficult as use of this component of the SWH approach was not applicable in most lessons observed. During two observations, she was observed providing instructions describing to the students that they would develop claims and must provide evidence for these claims based on their investigation. However, she also stated that students had not been given detailed instructions as to how their claims should be written, reflecting her desire for students to make choices. While this strategy appears to indicate that Sofia did not play an active role in assisting students in developing an understanding of how to develop claims and evidence, she reported that students would discuss their responses to the SWH template and share the questions, tests, claims, and evidence they had developed. She noted that she was not sure if this had helped students to understand the process better, but reported that students did appear to benefit from this, providing the following example:

> [When] we go through the claims and you can see them kind of nodding when one of the stronger groups, or one of the groups that is really good at writing down their thoughts, will say something and they will be nodding and thinking "Oh yeah, I was the same way" but they might not have necessarily wrote it down the same way.

Classroom Culture

Sofia typically created a respectful, yet challenging classroom culture in which students were encouraged to participate in activities and share their ideas resulting in most lessons receiving a rating of four in this category. The classroom culture was observed to promote student dialogue, including the initial lesson prior to implementation of the SWH approach. In addition, Sophia reported that there was increased use of discussion in the class during the year.

Throughout this study, Sofia demonstrated both the understanding and skills needed to promote student dialogue. While both the initial and final lessons observed included extended discussion, including students commenting constructively on others' ideas, in the initial lesson Sofia often initiated the student to student talk by asking for comments on what another student had said. In contrast, in the final lesson student dialogue occurred with less intervention from Sofia. In response to being asked what she had done to develop discussion among students, Sofia discussed the improvement in classroom discussion, explaining that:

> [I have done] a little bit. I will, well not as much lately because they're doing a better job, but I used to [say] 'Well Jason had a question', and he'll say it again and then somebody will answer it…. And then I'll throw in things like 'Well what do you guys think about what Haley just said?', ….But now they've gotten better about [it] … But yeah, at the beginning when we first started discussions that was, I would throw those things in more often and its still not great, they still like to talk over top of each other and get loud from time to time.

As Sofia explained in the above passage, she was aware of the need to intervene more often to promote student dialogue earlier in the year. While her understanding and ability to promote student discussion likely improved during the year, these comments also indicate that she began the year prepared to engage students in talking about their ideas. This reflects on the strong preparation that Sofia claimed to have had and that she was not being asked to do anything differently.

Sofia also demonstrated an ability to effectively deal with individual students during these discussions. While there are often students in a class who are more eager than others to participate, Sofia would call on those students who had not participated in the discussion and push them to contribute their ideas. Sofia elaborated on this in describing how she needed to continue working on her questioning, stating that:

> Well questioning of course, I mean just making sure that I keep pushing them and don't let them get away with I don't know answers. There's a couple of kids that tend to shut down, so I might if they say I don't know, I say "ok I'll be back to you, so make sure you listen to the next person because I am going to come back to you" and that usually works. Sometimes they are still like I don't know and it's one of those pick your battles, have them throw a fit or just kind of move on. And usually if I say "ok but I'll be back to you" if I come back to them they're ok and they will answer or they will have an idea for the next question or the next discussion or thought or whatever. Or maybe if they just have this bad class period let them go and you can kind of tell by their body language and such and then the next class period come back to them and they are fine, and they will participate.

In discussing her strategies for getting those students who were not as eager as others to participate in discussions, Sofia exhibited an understanding that seems very advanced for this stage in her career. This again reflects on the high level of preparation that she believes she received in her teacher preparation courses.

Beliefs about teaching and learning

Sofia's beliefs about teaching and learning did not appear to change significantly during the course of this study. However, her beliefs provide insight into understanding why she was able to effectively promote the use of inquiry in the classroom through the use of the SWH approach.

Teaching

Sofia initially responded to the request to develop a metaphor describing her role as a teacher with the idea that she was a juggler, stating that "*Because you start with those three things, you're supposed to meet student needs, and make sure that the class is working for them. But then they start throwing in meetings and reading strategies and you've got to balance all of these things and still make class operate*." As Sofia was beginning her first full year of teaching, this response may indicate that she was trying to deal with both helping

students to learn science and deal with the many other responsibilities that come with teaching.

Four months later Sofia provided a similar metaphor, that of a circus ring master, but noted that the metaphor had several different meanings and "*can change from week to week*" depending on how things are going in the classroom. She felt that during certain weeks "*I feel like a circus ring master, trying to keep the circus from complete chaos.*" In this case, she may have been referring to the many responsibilities that must be juggled in addition to teaching. However, at other times Sofia felt that as the circus ring master she was focused more on student learning, as she stated that *"Calmer weeks maybe I feel like the ring master meaning I introduce new acts (activities) to keep the students interested and provide some background info so the "acts" make sense and the students can find value in them.*"

Three months later Sofia believed that her teaching metaphor had not changed. In addition, she found the exercise to be the "*the most impossible question*" as "*It's just one of those questions where I think 'Oh is there a right answer to this? No. Is there a wrong answer? Maybe? I don't know.'*" This difficulty that she experienced in developing a metaphor may reflect her lack of classroom teaching experience; she may have still have been developing her beliefs between what is theoretically ideal and what she feels is achievable in the classroom.

Sofia's responses to the metaphor task indicates that she may have been clearing one of the biggest hurdles that all beginning teachers face, that of managing the chaos of the classroom while juggling her many teacher responsibilities. She seemed able, at least at times, to focus her efforts on the main purpose of education – student learning, while still meeting the multitude of other challenges in the class. This is a change that one would expect

almost every beginning teacher must make; the alternative being that they will leave the profession or remain a very ineffective teacher. The majority of teachers involved in the SWH professional development are more experienced, and thus support for beginning teachers is not a primary goal of the support efforts. While there is not sufficient evidence to support a claim that implementing the SWH approach with assistance from Tom caused Sofia to make this important teacher change, the support that she received may have assisted her in this growth.

Sofia also provided additional insight into her views about teaching during the interviews. Given Sofia's claims that the teacher preparation program she attended emphasized constructivist-based learning and teaching, it was not too surprising that she expressed concern that she not give students' answers, stating that "*they still want to know what the answer is from me, so and for me not giving them the answer is still sometimes hard… but I try really hard not to.*"

Sofia also described how she does not want to have students completing the SWH student template as she would, stating that "*I don't know if I tend to be vague cause I don't want to lead them anywhere…. I know what I would do if it was me filling out the sheet I guess. But that is not necessarily what they would do and so then that is where you, I try not to say much because I don't want to have them filling out the sheet the way that I would do it.*" This statement may reflect some confusion between her understanding that as a teacher she should not give the students answers, with her role in assisting students to learn. Her belief that she should not lead students anywhere, if enacted, would leave students to struggle to develop understanding by themselves, a role not supported by most who argue for the use of constructivist based instruction. Yet, while Sofia spoke of not leading students, her actions

indicated that she did provide guidance to the students. For example, she noted that in assisting students in learning how to use the template "*mostly I try to have them explain it to each other and if there are a few blanks I might ask a few more questions, but they tend to do a pretty good job.*" Thus, Sofia appears to have assisted the students in helping each other develop understanding by providing key questions as needed.

Learning

Although Sofia reported that the preservice program she attended stressed constructivism, surprisingly her statements regarding learning did not directly reflect this. Indeed, the most direct statement she provided regarding how students learn was more congruent with multiple intelligence learning theory as Sofia stated "*they're all different, some of them they need to read it, some of them they need that hands on, some need both, some need to hear it.*"

While this statement reflected a belief that students learn differently, Sofia also believed that there were aspects of learning that all students had in common. For example, she expressed a belief that regardless of her actions, learning was ultimately the students' choice as *"No matter what I throw at them or what opportunity there is in class, if they don't want to do it, I can't really make them learn it.*" Although this statement can be interpreted in many ways, including that Sofia believed student learning is beyond her control, her actions as reported previously, suggest otherwise. Rather, Sofia believed that lessons should engage students in finding relevance in the concepts being studied, as she explained "*It has to be something that they think is relevant to their world, like it is either something that they think is going to help them in the future.*" Yet she also realized that this would be a difficult task as "*If I did a neat demonstration at the beginning of class and then handed my eighth graders a textbook it would be like 'Who cares?' So no, that's not how they are going to learn."*

Rather, Sofia's statements appear to reflect an underlying belief in students' active participation, both hands-on with concrete materials and mentally though discussion, in constructing knowledge rather than transmission of knowledge from teacher to student. For example, as previously reported, Sofia modified the Physics Olympics activities, explaining that the changes were made "*thinking that it would be more of a challenge. Because if I give them step by step instructions there won't be any variety, there's nothing there to make them think really other than can they follow directions."* This belief was also reflected when Sofia described how students would discuss many different aspects of the activities months after these had been completed. For example, in recalling how the students could discuss forces in relation to the egg drop activity, Sofia stated "*So, obviously they learned something as they were building and as they were working and there was some discussion and… [there] was very little use of the textbook for any of the different competitions."*

In addition to expressing a belief that learning occurs when one sees relevance in the concepts, Sofia also believed that learning should result in one using the concepts in real life. In referring to her personal learning, Sofia stated "*if I can take that knowledge and put it in a different setting or a different, you know take it out of the science room and use it somewhere else, then that is something I learned.*" This view was also reflected several times when she described what she felt students had learned during the Physics Olympics activities. In discussing her role as a teacher, she provided an example of students relating an activity with model cars and ramps to the cars they would soon drive. Most students lowered the ramp to reduce the cars speed; however, one student placed crumbled bits of paper between the car and wheels to act as brakes. In the following passage Sofia recalled:

> They did a really good job of tying that all into the real world. Most of them are getting ready to drive and so I felt that they really went out of class thinking about things that they are going to use. They talked about bald tires and they talked about gravel roads versus paved roads and how those wear on, so they took a little bitty toy and they applied that to something that is really going to matter to them, especially in a couple of years when they are driving. And I don't think, I mean I might be wrong, but most of them seemed very interested in it and I don't think that it is something that they are forgetting.

This passage reflects Sofia's belief that learning occurs when students are actively engaged, both physically and mentally, in activities that assist students in finding relevance to the concepts being studied. In addition, it appears that this situation arose unexpectedly as the student completed the task in a different manner than most other students did. Yet Sofia used this example to promote discussion among the students leading to an exciting learning opportunity.

Summary

Sofia began the study with relatively effective pedagogical practices and claimed that the actions she was being asked to take in utilizing the SWH approach in her classroom, were no different than what she had learned in her educational preparation program. She demonstrated strong questioning practices and the ability to promote student to student dialogue. While Sofia was using 'cookbook' type activities at the beginning of this study, she began to develop new or modify existing activities while using the SWH approach. In addition, she reported that there was less reliance on use of the textbook during the course of this study. Perhaps the most significant change in Sofia's practice was that she reported spending much more time thinking about the questions she would ask students and how she would handle their responses as this study continued.

Sofia's pedagogical practices reflected her beliefs about teaching and learning in that students should play an active role in developing their understanding so that they could use this knowledge later in life. Although there were no changes in her beliefs during the course of this study, these beliefs may have supported Sofia's continued use of the SWH approach despite her initial struggles. Although she had difficulty in developing lessons and activities dealing with the abstract concept of atoms and elements during unit one, Sofia took actions without Tom's assistance and developed a series of activities to use during the following unit. Included as part of this, she modified activities to provide students with more opportunity to develop the procedures themselves resulting in situations where students were able to discuss this knowledge in scenarios relevant to their lives.

Martha

Unlike the other teachers in the study, Martha had fifteen years of classroom experience, twelve of those teaching elementary school science in addition to language arts. While her preservice preparation was minimal, both in science content and methods courses, she had voluntarily participated in other professional development projects which involved the use of inquiry-based instruction. While Martha's lack of content preparation was evident in the lessons observed, her overall ratings were surprisingly high (see Table 3). It should also be noted that, as described in the methods section, Martha also implemented the district mandated Reading First program during the course of this study. Thus reported changes in Martha's pedagogical practices and beliefs about teaching and learning are assumed to have occurred in the context of implementing both the Reading First program and the SWH approach with Tom's assistance.

Practice

Although there were no changes detected in Martha's pedagogical practices based only on classroom observations, she reported many changes in her teaching during this study compared to previous years. In addition, there were several areas in which Martha struggled to design and implement lessons so that students could learn through inquiry. Her inadequate preservice preparation and certain beliefs appear to have played a major role in the difficulties that she experienced.

Table 3. Martha's ratings

Lesson	1	2	3	4	5
Capsule description	low 3	high 3	high 3	low 3	high 3
Design	3	4	4	4	4
Implementation	3	3	3	3	3
Content	2	3	3	2	4
Classroom culture	4	4	4	4	4

Design

Overall Martha received high ratings for lesson design (see Table 3) as her lessons followed a general pattern in which the class began with a review as an introduction to the new lesson, followed by at least one activity that engaged students both physically and mentally with time allotted to discuss and make sense of the results. In addition, in many lessons, students developed a class list of questions about the concepts being studied to which new questions are routinely added.

The initial lesson was ranked lower due to the laboratory activity that was used having a very limited role for students in developing the procedures or interpreting the data compared to activities used later in the year. Although subsequent activities did have an increased role for the students, and may indicate a change in the type of activities Martha used, it is not possible to make this claim as use of poorly designed activities was only observed this one time.

While there were no major changes detected based on classroom observation, Martha described changes she believed had occurred compared to how she taught in previous years. These include the integration of language arts and science instruction, less use of the textbook, an increase in the number of hands-on activities used, an increase in the student involvement in both deciding what questions are to be answered and how this was to be accomplished, and an overall change in how Martha planned her lessons.

One of the major changes Martha reported in her pedagogical practice was that she integrated language arts and science instruction to a great extent. For example, the Read Aloud strategy was used during class time allotted for language arts as students found answers to questions they had developed about magnets during science instruction the previous day. Conversely, during class time allotted for science instruction Martha emphasized proper grammar and reported that she had "*stress[ed] the use of complete sentences and answering questions with complete thoughts and explanations. The students have grown to learn that it is expected to write well in any of their classes, not just reading and language*."

The extent to which instruction in the two areas was integrated is best reflected in a story Martha told. Martha recalled that one day a student asked " '*Mrs. (Martha), now is this*

science class right now or are we in reading class right now?' We have schedules, but he said 'I'm not sure, we've been doing all this science stuff in reading and all this reading in science.' " It would appear that, for at least this one student, class time was not devoted simply to learning science or language, but rather both.

This change appeared to have occurred as a result of Martha's voluntary implementation of the SWH approach and district mandated implementation of the Reading First program. Martha noted the significance of the Reading First Program in pushing her to integrate the two subjects, reflecting that "*with the Reading First [program] it's really changed how I teach reading and language separate from science; there isn't a whole lot of separation any more*."

Yet, the implementation of the Reading First program may not be the only factor responsible for the integration of language arts and science instruction in Martha's classes. While the Reading First program, with an emphasis on using books other than texts to help students learn content, seemed to have caused the integration of science instruction into the language arts lessons, the program does not emphasize writing skills. However, the SWH approach does stress the use of writing, although the focus is more on writing as a mode of learning, rather than on the specific skills of writing. It appears that Martha chose to focus on the use of writing skills as she reported that "*stressing the writing skills was the easiest part of the SWH approach,*" and that "*Now I have the chance to teach writing and language skills in science as well as during reading and language class. It has made it easier to teach across the curriculum*." As Martha's primary teaching responsibilities and training related to reading and writing, rather than science, it may be that she interpreted the writing component of the SWH approach to be that of writing skills. Nevertheless, it appears that use of the SWH

approach played a significant role in Martha integrating language arts instruction during science lessons.

Martha's change in how she taught these two subjects also appeared to lead to changes in her beliefs about integrating them. In the context of discussing how students read science related books during language arts lessons, Martha related a specific instance when she realized how effective integrating the language arts and science content was, "*I can remember just in my mind that day thinking, 'Wow, why wasn't I doing this all the time? Connecting the science content with my reading.' And that was one thing that I remember it really kinda striking me as 'Why wasn't I doing this all along?*'" Martha believed the reason was her preservice preparation, stating "*Because you are not taught that, that's why. You know, you're taught that you have 90 minutes for reading and language and you have an hour and ten minutes for science in the afternoon*." Reflecting on the how her instruction had changed this year, she continued "*but you just have to kinda feel your way around and figure out that 'Nope, they really kinda belong together*'." (DHi1)

While the concurrent implementation of the SWH approach and the Reading First program appeared to have produced significant changes in Martha's pedagogical practice, it should be noted that this might not have occurred if the Reading First program had been voluntary rather than mandated. When asked if she would have integrated language arts and science instruction if not required to use the reading First program, Martha stated that "*I don't know that I would have had that strong of a push to actually get the ball rolling to see and then to start seeing how it really did work well. So I'm sure I wouldn't have been doing all the things that I am now had I not been told you are going to do it*."

In addition, the role that Tom played as the professional development provider in supporting Martha throughout this change appears to have been significant. Martha reported being initially concerned about having to implement the two approaches concurrently given that implementation of the Reading First program was mandated by her school district. It would seem reasonable to assume that many teachers would not have chosen to implement the SWH approach given the district mandate. However, Tom was able to provide support for Martha as she recalled how Tom explained "*how much the Reading First initiative and the inquiry science, how much it was all going to blend together.*" Reflecting on the year and how well the implementation of the two had worked, she noted "*and it did*."

Martha also reported that she was using the textbook less this year. This claim is supported as use of the textbook was never observed. Martha attributed this to the Reading First program emphasis on the use of non-fiction trade books. However the SWH approach also places less emphasis on the use of textbooks for student learning; textbooks are utilized more as an expert source for students to compare their ideas to rather than a place to begin instruction.

Regardless of which program resulted in her using the textbook less, Martha was aware of the change in her planning, stating that "*it was a lot easier just grabbing a text book and saying "ok open up to page four and lets go with it.*" Yet despite the increased difficulty in planning, she believed that the resulting changes in her teaching had impacted student learning, stating that "*I don't think they learned as well (using the textbook) but on the part of the teacher it was easier.*"

In addition to using the textbook less, Martha also reported that there had been a change in the number of hands-on activities the students participated in, explaining that "*I was doing*

some hands-on things, but now I am doing many, many more." As this study did not include data from previous years, it is not possible to confirm this report. However, the students were observed participating in at least one hands-on investigative activity during each lesson, suggesting that Martha's reflection is accurate.

In conjunction with utilizing more activities, Martha also reported a change in the students' role; they now help develop questions that the class may reflect on. She was now "*letting the kids help to decide with it, and they're coming up with questions that they need to find the answers to.*" This claim can be supported as during several observations students developed lists of questions that they had about the concept being studied.

In addition, Martha also reported that when students come up with questions, she will often say "*Well how can we set up an activity to figure that out?*" While there were no activities observed where students designed the procedure themselves, in several instances they were actively involved in developing the procedure. For example, during the electricity unit, the students were given only the basic instruction of using the provided materials to light the bulb. In another activity, designed to compare the amounts of fats in meats, Martha had the students discuss how this might be accomplished and develop a procedure, which she and other adult assistants then carried out for safety purposes.

As a result of having students develop their own questions, Martha spent additional time at school preparing activities, materials and information for the next day, reporting "*I have probably spent more time at school this year than I have in the 15 years I have taught*" so that she can rewrite lesson plans each day as "*wherever we left off then I can plan what we need to do the next day.*" For example, she brought in many different library books on magnetism which she had gotten from the Read Aloud described previously.

The changes in how Martha planned activities was accompanied by change in the way she perceived herself as a teacher. In discussing the changes in her classroom, Martha reported that the students were "*doing a lot of things themselves and I guess my role, I'm not the dictator anymore. I don't know that I ever was, but it's not just what Mrs. [Martha] says, just do this because she said so. A lot of the things that they're doing now is because they want to know the answer to it*." Reflecting on these changes, Martha continued, *"[it's] been a big change because usually I'm pretty structured with stuff and it's been a little bit more chaotic I guess, structured chaotic I guess*."

Yet these changes were not always easy for Martha mentally, as she explained "*it can make you nuts sometimes too because you are not really sure what you're going to be doing the next day*" and that it "*is taking some time to get used to not always knowing for sure where we will be, or what we will be talking about for the next day's plans*." Yet as she felt that the students were benefiting from the new ways of teaching, she appeared to have become more comfortable with the seeming lower structure level, noting that "*Surprisingly enough, you know, there's a few days when you really fly by the seat of your pants but the kids get so much out of it*."

This positive attitude Martha displayed despite the sometimes difficult changes she was undergoing, is reflected in the following story she told Tom. As Martha was spending more time planning compared to years previous, her husband had asked that she do what she could at school and not put in the extra time. One Sunday he asked her why she was so excited about getting ready for an activity the following day. The following passage is how Tom relayed the story "*She told him it was because she was just as excited as the kids to see what would happen and what they would say to explain what was happening."* Martha explained

to Tom that *"I'm hooked on doing this stuff and am always thinking about what to do next, and how to change something we did last time*."

Implementation

All Martha's lessons observed received an implementation rating of three, indicating she neither excelled at or experienced extreme difficulty in enacting lessons so that students may increase their understanding of the concepts. In addition, these ratings reflect that there were no major changes observed in the implementation of Martha's lessons; in addition, Martha did not report any changes. That Martha's verbal interaction patterns did not significantly change is not unexpected; Tom did not actively work with her on this practice as he felt enough had been done in previous professional development activities.

Martha's verbal interaction patterns, including questioning, are best characterized as inconsistent. At times she asked many questions requiring students to generate novel responses and asked for clarification or elaboration of their responses, especially when leading students toward the days activity or while involved in the investigations. However, at other times, especially during review sessions that begin most classes, she asked many rhetorical questions or questions requiring yes/no or short answer responses. In addition, she was inconsistent in use of adequate wait time one and in the majority of cases did not use adequate wait time two; rather she repeated students' answers or asked another questions immediately. However, Martha did exhibit positive non-verbal behaviors designed to encourage student response, including smiling, raising of eye brows and looking around the room.

In general, Martha's classroom management was reasonable in that the students were on task and disruptions were quickly handled with a minimal loss of class time. However, one

aspect of her classroom management may have contributed to the difficulty she experienced in developing a classroom culture that encouraged student dialogue; students were always observed raising their hands to get permission to speak. This may indicate that part of Martha's classroom management practices included controlling when students talk. This expectation was made clear during the final observation when Martha told a student that he should raise his hand for permission to speak.

Another difficulty that Martha appeared to encounter involved the number of activities that were being implemented. As previously reported in the section on lesson design, Martha reported that she was using more hands-on activities this year than in past years. While the use of hands-on activities that engage students mentally is a fundamental aspect of inquiry, in Martha's case she may be attempting too many activities for a given unit. Several instances of this were observed as Martha began the next activity when it appeared that the students had not yet grasped the initial concept enough to warrant moving on. For example, during the unit on electricity students spent the first day trying to light a bulb using a battery and wires. The students did not appear to understand the fundamental concept of the circuit and why the two wires had to be connected in a certain manner. While Martha acknowledged that the students did not understand why the bulb would only light in certain conditions, rather than conducting more investigation into the conditions necessary for the bulb to light, Martha began an activity that involved testing items to see which conducted electricity. To accomplish this task students used the circuits that they had developed but did not understand. Thus, in implementing that days lesson she should have focused on developing the students understanding of the fundamental concept rather than moving on to the next activity.

Content

Throughout the year Martha covered a great number of concepts, including certain aspects of geology, animals and their adaptations, electricity and magnetism, mass and volume including density, and nutrition. She exhibited an adequate understanding of the material she was teaching, yet did make errors regarding both the science concepts and the level of detail that is likely to be developmental appropriate for the students. For example, in one lesson Martha related the vibration of atoms in a solid as equivalent to the movement of atoms in liquid and gases. This is conceptually incorrect as atoms in solids vibrate but do not move freely while atoms in liquids and gases do move past each other. While this is incorrect as far as the content is concerned, what is more concerning is that this is not appropriate content for fourth grade students; conceptualization of this idea requires them to imagine particles that cannot be seen, a task their brains are not likely developed enough for yet. This example was not an isolated case as, based on observations of other lessons the students had studied electrons, protons, magnetic fields, chemical nomenclature, and hydrogenation during the year; all concepts that are difficult to present in a manner that could be developmentally appropriate for these students. Overall, as can be seen in the content ratings (Table 3), Martha was inconsistent in her ability to choose content and implement lessons so that the students are likely to increase their understanding of the fundamental ideas.

The difficulty is not surprising as Martha's primary teaching certification is in reading and language. As a result, she has only had one science methods course and taken one science course in college, biology, and that was her own initiative. Thus, as she stated, "*I actually learned most of what I'm doing now just teaching it*." She also acknowledged often covering what interested her rather than what was required by the district and stated that one

of the things she required in order to better implement the SWH approach was "*to get more of a knowledge base in a variety of elementary science areas that line up with our district's standards and benchmarks*."

Martha also experienced difficulty incorporating the use of another important aspect of the SWH approach, that of involving students in developing and supporting claims based upon evidence derived from their experimental data. She was observed asking the students to develop claims in three of the five lessons, however, the term evidence was not used. Neither did she use the term evidence during interviews. Instead, she used the term facts when referring to the students support for their claims, stating "*They knew that they had to prove their claim, they couldn't just make the claim. They had to have some facts to back it up or they could show me*."

One possible explanation is that Martha was using the term evidence in lessons and was simply not observed doing so in the relatively small number of observations that were made. Tom reported on several occasions that Martha had stated she was using the claims and evidence terminology. For example, Tom related the following story from Donna about a students response when asked what they meant by facts, "*The kid said 'You know, facts. That's when you make a claim and then have to back it up with evidence. Evidence is the fact(s), and you have to be able to prove it.*"'

However, the lack of observation of the use of the term evidence may also be explained by one of the changes Martha made to the SWH student template in order for the students to more easily understand it. Martha removed the step where students would state what evidence had been used to develop their claim. Without this requirement, it is not surprising that the use of the term 'evidence' was not observed. In addition, Martha and the students

seem to use the term facts interchangeably with evidence, although this was not observed in any lesson either.

That students were not required to state the evidence that had been used to develop their claim is a concern as this could lessen their developing an understanding of the tentative, changing nature of scientific knowledge and how scientist's ideas can be viewed as arguments supported by evidence from observations and experiments. However, the data provided by Martha indicated that the students were developing some understanding of claims needing to be supported, be it by facts or evidence. Thus, it is not clear as to what degree Martha was effectively implementing the argumentative aspects of the SWH approach.

Another difficulty Martha created occurred when she removed the requirement that students compare their ideas to others, typically an 'expert' source such as the textbook. Thus the students appear to not have been given the opportunity to find further support for their claim or be exposed to a more scientifically valid explanation that might lead to a change in their understanding of the concept.

A potential explanation for this, is that Martha appeared to not understand the relationship between students developing their claims and then examining other resources to compare their ideas with. In a lesson dealing with nutrition, the students examined the amounts of fat collected from several cooked meat samples and were to determine which was the most healthy in relation to the amounts of saturated and unsaturated fats. One would have expected the students to first develop their claims and then to consult an expert source. However, Martha gave the students a table which described the fat content of various meats prior to the development of claims. The data on the table were discussed, including which

meat was most healthy based on fat content. Martha then asked if they thought the figures on the table were accurate and led the students in determining if the table was accurate based on the data they had collected. The result appeared to be that a claim was developed that the chart was accurate, and not which meat is most healthy.

While no improvement was detected in Martha's pedagogical practices relating to content, she reported a change in the students' role in choosing what content was studied. While she had stated early in the study that part of her task as a teacher was to get students interested in "*my content*", four months later she stated that this had changes as "*a lot of the responsibility now and a lot of the choices are falling back on the kids, they're choosing, you know they've got questions, they're choosing what the content is where that used to be me doing all of that. That's changed a lot*."

This is not to say that Martha allowed the students to determine the general concepts to be studied; she still chose which major concepts, such as magnetism and electricity, were to be studied. Rather, as had been reported earlier under the design category, she had the students develop lists of questions about what they want to know about each concept. Martha then worked to help them get answers to their questions, for example, by reading books or incorporating their questions into a planned activity.

This perceived change in her practice was accompanied by a change in Martha's beliefs about teaching and learning related to student input in determining what ideas are to be learned. She explained that her decisions regarding the ideas to be learned were based much more on what the students wanted to know when compared to how she had typically made these decisions noting that "*I also feel that I am much more driven by what the students want to know, rather than what I want them to know*." It is also important to note here, that Martha

recognized that what she was doing while implementing the SWH approach was different from the way to was instructed to teach science when she was undergoing her teacher preparation as she states "*This is a huge change from what I was taught to do in the classroom in college*."

Classroom Culture

Martha created a respectful, yet challenging classroom culture in which students were encouraged to participate in activities and share their questions and ideas resulting in all lessons receiving a rating of four. Martha routinely used students' wording when writing ideas on the board, often asking for clarification or suggestions as to how the ideas should be stated. This served both as language instruction and to emphasize that the ideas being discussed were the students.

While the classroom culture created in Martha's classroom supported the use of inquiry, she experienced difficulty in promoting student dialogue in the classroom. Tom reported several times that he was working with Martha to assist her in implementing this important aspect of the SWH approach. Yet, despite his assistance, no increase in the amount of student dialogue was observed throughout the year. As reported previously, Martha's classroom management may have inhibited student dialogue as students had to gain explicit permission to speak. In addition, as she often repeated students' answers, it was less likely student dialogue could develop.

In addition, Martha's previously reported struggles in choosing developmentally appropriate content may have also contributed to the difficulty she experienced developing student dialogue. In the last observed lesson, students were studying the general properties of solids, liquids, and gases. In contrast to prior observations, there were several occasions

when students commented directly to others; this often involved conflicting ideas about the physical state of an object such as silly putty. Yet Martha was not observed to utilize any teacher behaviors that would promote student dialogue. Rather than allowing the interactions to continue, Martha would interrupt and repeat what one of the students had said.

One has to wonder then why the students were attempting to engage in dialogue with each other when this was not seen in other observations. A possible explanation is that in other lessons Martha often dealt with potentially developmentally inappropriate concepts such as electrons and magnetic fields; in this case, the students could easily understand the general properties of solids, liquids, and gases and thus were eager to share their ideas. This would imply that, in addition to working on the teacher behaviors that may be limiting student dialogue, Martha also needs to choose more developmentally appropriate content in order to develop student dialogue. If Martha were to experience more situations in which students were eager and able to engage in dialogue, she might then relax her managerial control and encourage student dialogue.

Beliefs about teaching and learning

In the previous sections, changes in Martha's beliefs about teaching and learning have been reported as they related to the appropriate area of pedagogical practice. In this section, additional changes in Martha's beliefs will be discussed that appear to have occurred during the course of this study.

Teaching

In response to the task of developing a metaphor to describe her role as a teacher, Martha initially described herself as a tour guide in that "*I can show them all of the information but the trick is to get them interested in each attraction of my content*." While this is only one

sentence and there was no further discussion regarding this response at the time, her metaphor may best be interpreted as reflecting a teacher-centered understanding of science education. Martha referred to the concepts to be learned as "*my content*" and viewed her role as presenting the information to be learned, possibly reflecting belief in a 'transmission' mode of learning.

Approximately three months later Martha's thoughts on teaching appeared to have begun to change as she stated that "*I could jump up and down and do cartwheels all day long trying to get them to learn something and unless they want to get to that destination they're not going to get there*." In subsequent statements, Martha described how the students were now making choices and how this had changed her role, reflecting that "*I'm not just ringing all bells and whistles hoping that they all pick it up. They're starting to make those choices themselves, whether they are reading at a second grade level or at a ninth grade level. They're making those decisions*."

Martha's teaching metaphor that was developed at this time also reflected a more student-centered understanding of science instruction; she was an air traffic controller and the students were the pilots. Martha described this metaphor in greater detail stating "*I can give instructions and needed information to them and hope they follow the right path. Sometimes things get in the way, and we must figure out a different route, but hopefully still get (to) the intended destination without crashing*." While she still spoke of providing information, her statement suggests she sees a more active student role as they can help in figuring out new paths when learning difficulties arise.

In a subsequent interview, Martha explained the differences in her two metaphor responses, stating "*When I wrote the one with the air traffic controller,… I was thinking -*

I've got all these different kids (with) different abilities, and they go about things in different ways, but they're still figuring out a lot of the same answers - they're getting to the same point." Martha appears to have begun to perceive that her role as a teacher was working with students' individual differences in order to promote common learning goals. In addition, she believed that allowing the students to find answers to questions that were important to them could help accomplish this, as she reflected "*I guess I am starting to focus more on the different abilities and how I can get them all, by using different, by using like the SWH, finding out the answers to their own questions. I'm finding that it's working better than I anticipated*."

Thus Martha appears to have undergone changes in her beliefs about teaching at this point of the study. While still speaking of the importance of student interest in learning, her comments suggest that she no longer perceived her task as directly increasing students interest, but rather something to be developed in them. Martha believed that allowing students an active role in determining what was being studied, specifically by allowing students to find answers to their own questions, was an effective method to increase student interest. In addition, she had begun to perceive students as individuals that will require different approaches to learning a concept, thus requiring that she work with students as individuals, rather than treating all students the same.

However, Martha returned to the metaphor of tour guide in the written response provided at the end of the study stating that "*I can show them all of the sites and information, but they are (not) going to learn anything about what I show them or tell them unless they have an interest in it or a question about it*." Understanding of this metaphor is difficult as there was no follow up interview conducted to allow Martha to elaborate on this statement. Thus, while

trying not to read more into the statement than is there, it appears that although Martha returned to the initial metaphor of tour guide and stressed the role of student interest, she also integrated the belief that student interest can be developed by allowing them to develop their own questions; a belief that she appeared to have developed during the course of this study.

Learning

Martha initially defined learning as taking "*what someone is presenting to us and understanding it, and taking it in and maybe using it.*" She provided a similar response approximately three months later writing that learning is "*taking in what's around you or being presented to you and understanding it*." Given that both responses related learning as involving understanding what one is presented with, one plausible interpretation is that Martha viewed learning as a process of information transfer. This interpretation is consistent with the teacher-centered beliefs reported previously that Martha held early in the study.

However, as Martha gained more experience using the SWH approach in her classes, she reported questioning her prior beliefs about teaching and learning, stating that "*I think in the first few years I was teaching I thought I was teaching these kids and they were learning. But now in hindsight you look at that and you think 'Were they really learning? Or were they memorizing a lot?'*"

Martha's third response defining learning also reflected a change toward a more student-centered view in that she believed that "*Students learn through their experiences and understanding of things around them. The more things that they are exposed to, the more they are going to learn and understand*." In a subsequent interview, Martha's statements reflected a belief that students require experiences with the concepts they are to learn, and not simply to be presented with information. She states "*I've seen the kids now when I'm*

questioning them. 'Why do you think this? How can you make this claim?' They're remembering and they're answering it. Not from a textbook, they're answering it from what they have experienced."

This apparent change in Martha's beliefs about learning seem to have been facilitated by the dialogue she was engaging in with the students. Upon further reflection on the changes she had undergone in her beliefs, Martha explained importance of talking with the students about their ideas.

> I know that they've always needed the experiences to understand, and the hands on experiences and so on are always successful. But I guess I haven't realized how much or how important that is until I had the conversations with them now. And when they're talking to me like a miniature adult, rationalizing why they think what they think, it's been pretty awesome.

As Martha acknowledged, she had been exposed to the use of experience in student learning and how activities can play a crucial role in providing experience. This most likely occurred during the course of the previous professional development work she had been involved in. Yet it appears that by utilizing students' ideas as part of class, an important aspect of using the SWH approach, Martha was exposed to the students thinking and developed a deeper understanding in and belief for the use of activities in providing experience for students.

Martha also appears to have developed a deeper understanding of what the effective use of inquiry in the classroom entails. While she had participated in an extensive inquiry-based professional development program for several years prior to her involvement in this study, and thus would be expected to have a general understanding of the use of inquiry in the classroom, during the course of this study Martha made comments that suggested that while she did understand that the SWH was an inquiry-based approach, she also believed that there

were specific differences. For example, in discussing her understanding of the SWH approach, Martha stated "*It's still using the inquiry model with a lot of things but it's really emphasizing more the kids questioning, and figuring out the answers to their questions, figuring out ways to do that and then the writing*." Martha also perceived the SWH approach as moving beyond inquiry, in that it "*takes the inquiry science another step farther by stressing not only the importance of hands-on exploration to figure out answers, but also adding good writing, thinking, questioning, and reasoning skills to this*."

Yet all of the student actions Martha described and attributed to the SWH approach, and not to inquiry in general, are found in descriptions of inquiry in the *NSES* (National Research Council, 1996). She appears to have developed a better understanding of inquiry, yet attributed this new understanding to the specific approach she was using. A possible explanation arises from the previous professional development programs Martha participated in focusing on the use of kits and activities. In contrast, Tom's work with Martha was focused on assisting Martha in developing the pedagogical skills and understandings to effectively implement the SWH approach to inquiry. For example, that students should play an active role in generating the questions to be investigated, the methods of investigation, and engage in dialogue about their observations to develop possible explanations.

However, by the end of this study this distinction between inquiry and the SWH approach may have been resolved. While the following is only a brief statement and was not discussed further with Martha, her definition of inquiry, written at the end of the school year, seems to indicate a deeper understanding of inquiry – "*I see inquiry science as being a guide for letting students figure what the answer is to their question rather than having them sit down and read it in a book and accept that as fact. They need to question and understand, not*

memorize information." Martha appears to have integrated the understanding of inquiry she had developed while using the SWH approach into a more valid understanding of inquiry in general.

Summary

Based on classroom observation alone, very few changes were detected in Martha's pedagogical practices. However, she reported many changes in her practice compared to years prior to this study. While it was not possible to confirm that these changes had occurred during the course of this study, many of the actions that Martha reported were observed and thus the changes are assumed to have occurred.

One of the most significant changes that occurred was the integration of language arts and science instruction as a result of the concurrent implementation of the Reading First program and the SWH approach. As Martha observed the effects of this integration, her understanding changed from one of not believing that the two subjects could be integrated to believing that there was value in this strategy. In addition, Martha also reduced her reliance on the textbook as both the Reading First program and the SWH approach do not promote use of textbooks.

Martha also reported an increased use of hands-on activities with the students taking a more active role by generating questions they were interested in finding answers to and developing investigations to accomplish this. As a result of these changes, Martha also reported that she spent more time planning as day-to-day changes occurred based on student interests. Martha also reported that while teaching now seemed more difficult as she no longer felt in control of all actions occurring in the class, she was also very excited about the students' progress and enjoyed putting in the extra time required to plan lessons.

In addition to changes in her pedagogical practice, Martha's beliefs about teaching and learning appeared to evolve, becoming more student-centered. Whereas her initial comments suggested that as a teacher she decided what content students were to learn and then presented the needed information, she later professed a belief that teaching involved working with students as individuals; for example, by having students develop questions that they are interested in finding answers to. Martha also reported that she no longer believed that students learned by using just the textbook, but rather that they required experience with the concepts that they are to learn. In addition, her understanding of the use of inquiry in student learning evolved from one in which inquiry was perceived as the use of hands-on activities to a more educationally valid belief that inquiry also involves active participation by students in developing questions, procedures to test the questions, and discussion about what the results might mean.

Despite these changes, there were areas in which Martha struggled to implement the SWH approach. Although Martha had noted the importance of dialogue with students in changing her beliefs about teaching and learning, she was unable to promote student to student dialogue despite a focus on this area by Tom. Although Martha used many activities designed to engage students in exploring natural phenomena, her lack of content understanding and inability to choose developmentally appropriate content combined to create situations where the students appeared to not gain a deep understanding of the fundamental concepts. Martha also struggled to implement the use of argumentation as she did not appear to understand the theoretical underpinnings of the SWH approach. This resulted in removal of both the item requiring students to explain the evidence that supports their claims and to discuss what others believe as part of deciding the validity of their claims.

Chapter Summary

The case studies reported in this chapter portrayed three unique change processes that the teachers underwent. Based on the lesson quality descriptors used by Pasley et al. (2004) and described in chapter three of this study, Martha and Sofia designed and implemented lessons that were occasionally high in quality (high 3, 4, 5 capsule description ratings) and routinely were medium level in quality (low 3 and middle 3). In contrast, Fred's lessons were typically rated low in quality (1 and 2). While none of the teachers changed their overall pedagogical practice to the extent that ratings were judged to be significantly improved, two of the three teachers made important changes that suggests further improvement will occur over time.

Fred's case reflected the difficulties reported in the literature that many teachers have improving their practice. He began with the least effective pedagogical practice of the teachers involved in this study, including poor questioning and time management, use of activities that do not support inquiry, and placed emphasis on learning of vocabulary and facts rather than conceptual understanding. In addition, Fred believed that the degree of fun students' had was a condition and indicator of learning; a belief that was reflected by his actions in the classroom. Fred also held sometimes contradictory beliefs regarding teaching and learning. For example, while he perceived teaching as being a facilitator of learning he also believed that he should provide the needed linkages between what the students learn in class and how they could use it outside the classroom. As a result of both his poor pedagogical practices and beliefs that did not support the use on inquiry, Fred struggled to implement the SWH approach and was unable to make any changes in either his practices of beliefs and chose to only use the SWH approach for one unit.

In stark contrast to Fred, Sofia's case reflects the potential for a teacher who demonstrates effective pedagogical practices and holds beliefs about teaching and learning that support the use of inquiry. Although Sofia began the study with effective practices, including questioning for conceptual understanding and the ability to promote student dialogue, she experienced difficulties during the first unit in which she used the SWH approach. However, these difficulties appear to have been related more to the abstract nature of the concepts studied and Sofia's lack of experience in teaching these, rather than difficulty with using inquiry in general. Importantly, rather than abandon the use of the SWH approach as Fred did, Sofia spent additional time outside of class to develop lessons and activities for the next unit. Reflecting her beliefs about learning, Sofia modified a series of activities so that the students played a more active role in developing both the procedures and their understanding. Developing these activities allowed Sofia to focus additional attention to thinking about the questions she could ask students and the dialogue that she could engage students in regarding the concepts to be learned; an important change in order to more effectively promote inquiry and student development of conceptual understanding.

Finally, Martha's case reflects the difficulty in improving the practice of elementary teachers who typically have minimal preparation in both science content and science methods, and the improvement that can emerge when a teacher is involved in extended professional development programs. Despite her lack of preservice preparation for teaching science, Martha demonstrated surprisingly effective pedagogical practices throughout the study, suggesting that she had undergone changes within the context of previous professional development activities. Yet Martha still struggled to promote inquiry due to difficulties in accurately representing scientific concepts and concepts about science, selecting an

appropriate level of conceptual understanding appropriate for elementary school students, and promoting student dialogue. Despite these struggles, Martha used the SWH approach throughout the study and reported making many changes in both her pedagogical practice and beliefs about teaching and learning. For example, Martha reported feeling less in control of the class as she was now using many more activities in which the students were given an active role in developing the questions and how investigation were conducted. This reflected her beliefs about teaching and learning that appears to have evolved to a more student-centered view. In addition, Martha increased the amount of time she spent in planning instruction and may have developed a better understanding of the use of inquiry in the classroom.

CHAPTER 5. DISCUSSION

This chapter serves to discuss the results of this study in terms of how the teachers' pedagogical practices, and beliefs about teaching and learning, may have both changed and interacted to influence the extent to which effective implementation of the SWH approach occurred, while participating in a professional development program. Based on a growing recognition that teachers play a critical role in how effectively inquiry-oriented curricula are implemented, the main purpose of this study was to document changes in the teachers' pedagogical practice throughout the year. In addition, many scholars have argued that teachers' beliefs play a crucial role in the implementation of inquiry-based instruction and the extent to which their practice may change. Thus, a secondary purpose of this study was to document the teachers' beliefs about teaching and learning, noting changes that occurred throughout the year, and to examine the interaction of their practices and beliefs while implementing the SWH approach.

This chapter will therefore be organized around the two research questions:

1. What changes occurred in teachers' pedagogical practices, and beliefs about teaching and learning, as they implemented the SWH approach while receiving support in a professional development program?
2. What was the relationship between the teachers' beliefs about teaching and learning and changes in their practice as they implemented the SWH approach while receiving support in a professional development program?

Before addressing these research questions, several aspects of the professional development experience are reiterated. These include the fact that the teachers' involvement was purely voluntary in that they were not mandated to participate and could do as much or

little as desired. While the teachers were asked to use the SWH template to conduct a minimum number of investigations, and were provided information on and modeling of the practices needed to effectively implement the SWH approach, the teachers chose the specific practices to implement and when. Also, professional development was provided by a retired, experienced science teacher under the direction of university personnel, with the researcher not actively involved in these efforts and conducting the research at a distance as the location was hours from the university.

Changes in practice

Given that many of the conditions currently promoted as best practices were met in the professional development program, many changes in the teachers' pedagogical practices and beliefs were expected to occur, resulting in the design and implementation of higher quality lessons. However the results did not indicate a clear pattern of improved lesson quality for any teacher. Sofia and Martha were able to make and sustain changes in their practice that, when examined in terms of the changing emphases for teaching standards as articulated in the *NSES* (National Research Council, 1996, p. 52) and reviewed in chapter two of this study, suggest that they did make progress towards more effective implementation of inquiry-based instruction in general and the SWH approach specifically.

The few changes that occurred in Sofia's practice served to strengthen instruction which most closely reflected the "more emphasis on" standard of the three teachers. For example, the most significant improvement that occurred, spending additional time anticipating students' questions and responses in order to develop more effective questioning sequences, is consistent with a focus on student understanding and providing opportunities for scientific discussion.

The many changes in Martha's practice appear to have shifted her instruction towards reflecting the "more emphasis on" standard. For example, she reported that students now helped decide what questions should be investigated, demonstrating a shift from her maintaining responsibility and authority towards sharing responsibility for learning with students. Yet despite her progress, Martha was unable to promote student dialogue despite Tom's repeated suggestions and assistance.

In contrast to Sofia and Martha, Fred's practice most closely reflected the "less emphasis on" standard; for example, he focused on student acquisition of information and recitation of acquired knowledge even when not using the textbook. Although Fred had the greatest need for improvement in practices, the only change that occurred involved less reliance on the textbook – which he was unable to maintain throughout the year.

Thus the cases of Martha and Sofia provide further evidence indicating that teachers can effectively implement inquiry (Pasley et al., 2004) and make improvements in their practice (Luft, 2001; Richardson et al., 1991). In contrast, Fred's case provides further evidence indicating that many teachers implement inquiry poorly (Harms & Yager, 1981; Pasley et al., 2004) and are reluctant to change their practice (Prawat, 1992; Vacc & Bright, 1999).

While progress was made towards more effective implementation of the SWH approach by two of the three teachers involved in this study, consistent with previous research (Anderson, 1996; Johnson, 2006), a number of factors were identified that created barriers to change in the teachers' practice. These included issues related to the content to be learned, difficulties in promoting dialogue among students, and struggles in developing and implementing activities. However, Fred faced many additional barriers, including those

caused by a reliance on the textbook, poor questioning strategies and beliefs that knowledge of vocabulary and student fun were crucial factors in learning.

The role of beliefs in teachers' change in practice

Consistent with the literature on teacher change, the teachers' beliefs appeared to be reflected in their practices. While both Sofia and Fred's beliefs appear to have remained unchanged throughout the study, Sofia's were the most consistent with use of inquiry-based instruction of the three teachers while Fred's were the least consistent. In contrast, Martha's beliefs underwent many changes in shifting toward a view more consistent with the use of inquiry-based instruction.

The teachers' beliefs also played a significant role in the change process. The changes that occurred in Sofia's practice appear to have been generally consistent with her beliefs. For example, despite the effective instruction she exhibited initially, Sofia still struggled when first developing activities using the SWH approach. However, rather than return to using textbook laboratory exercises in the subsequent unit, Sofia modified published activities in a manner reflecting her belief that students should make choices about how best to accomplish the goals of the activity. While no changes in Sofia's beliefs were reported as a result of these changes in practice, the researcher would suggest that there was a refinement or strengthening of her beliefs as she perceived positive student outcomes from her evolving practice.

In contrast, the new practices Fred was asked to implement were generally inconsistent with his beliefs and created many barriers to implementing inquiry-based instruction. For example, teachers are urged to rely less on the textbook when using the SWH approach; this change is based on the great emphasis textbooks generally place on vocabulary and pieces of

information rather than conceptual understanding. However, Fred's rationale that use of textbooks was "monotonous" reflected his belief that students learn best when having fun. In addition, reflecting his belief that students must know the vocabulary, the activities that replaced use of the textbook maintained an emphasis on vocabulary and facts. Despite the lack of learning with understanding that was observed when the students were engaged in these activities, Fred judged the activities as worthwhile as the students had more fun.

Martha's beliefs appear to have supported many changes in practice while creating barriers to others. For example, many of the changes that occurred in Martha's practice involved activities and language. As Martha had previously been involved in professional development work emphasizing the use of hands-on activity kits, and given her primary role as a language instructor, the researcher would suggest that her current beliefs may have been established based on her previous experience. Thus it is likely that these new practices were generally consistent with her beliefs about teaching and learning. This interpretation is supported by Luft's (2001) conclusion that experienced teachers appeared to make changes in their practice that were consistent with their beliefs. In contrast, the promotion of student dialogue may have been inconsistent with her beliefs about management and control of the classroom and created a barrier to implementing this practice.

However, as a result of perceiving positive student outcomes resulting from the implementation of new practices, Martha's beliefs appear to have changed. Subsequently, she was able to promote student dialogue as reported by Martin (2007). The changes that had occurred in her beliefs during this study and subsequently may have led to the promotion of student dialogue being more consistent with her beliefs overcoming this barrier to implementation.

Time and classroom enactment

While the teachers' beliefs played a crucial role in the extent that their practice changed, the time they spent engaged attempting to implement the SWH approach in their classrooms also appears to have been an important factor. Scholars have argued that change is a complex process that may require several years for a teacher to understand the new innovations and develop mastery of the practices required to effectively implement them (Blumenfeld et al., 1994; Davis, 2003; Huberman & Miles, 1984; Loucks & Pratt, 1979). Success at changing teachers' practice and beliefs is also argued to be assisted by opportunities to enact the new innovations in the classroom (Arora et al., 2000; Krajcik et al., 1994; Peers et al., 2003), as classroom experience with the new practices provides the means for teachers to develop understanding of the "features, associated challenges, and strategies for meeting them" (Blumenfeld et al., 1994, p. 545). In addition, while numerous studies have documented the positive effect that increasing hours and duration of professional development have on teachers' practice (Porter et al., 2003; Supovitz & Turner, 2000; Weiss & Pasley, 2006), the teachers all received approximately the same hours of support throughout the course of this study. Therefore, it appears that the extent to which the teachers' practice changed was a function of the increased amount of time spent engaged in implementing the SWH approach in their classroom.

Both Martha and Sofia used the SWH approach throughout the duration of this study, utilized many activities employing the student template, spent additional time outside of the class preparing lessons, and read the materials that detailed the SWH approach and the practices required for effective implementation. In contrast, Fred attempted to use the approach for only five months, engaged the students in very few activities using the student

template, did not report spending additional time planning instruction, nor did he read the provided materials.

Martha and Sofia both reported positive student outcomes as a result of the changes they made in their practice while implementing the SWH approach. For Sofia this did not occur until the second unit reflecting the concept of time needed for change to occur. In contrast, after struggling in the first unit he used the SWH approach, Fred appears to have abandoned use of the approach attributing much of the difficulties to students not being developmentally ready. As the SWH approach has been demonstrated to work with students as early as first grade (Norton-Meier, Nelson, Hockenberry, & Wise, 2007) the approach can be assumed to be appropriate for his students. Rather, the lack of positive outcomes Fred perceived was more likely a result of the minimal time he put into developing the practices required to effectively implement the SWH approach in addition to the barriers that his beliefs created. If Fred had spent more time attempting to implement the SWH approach, he may have noticed improvements in student outcomes and continued further improvement in his practice.

Thus while this study only lasted for nine months, two of the three teachers were able to make progress toward more effective implementation of the SWH approach. A crucial factor in the extent that the teachers were able to improve their instruction appears to have been the amount time and effort given to implementing the new practices in their classrooms, not just support time.

Relationship between change in practice and belief

There has been much debate over the past two decades regarding whether professional development efforts should first target change in teachers' practice, beliefs or both. Guskey (1986, 2002) claimed that efforts to first change teachers beliefs have not resulted in change

in practice; rather, he argued that teachers must try first new practices, and if they perceive positive impacts on students performance, then corresponding changes in beliefs will occur. The changes that Martha made in her practice followed by changes in her beliefs supports Guskey's claim.

However, this view of change suggests that a teacher may attempt to implement any new practice and will only keep the ones that are perceived as leading to positive student outcomes. Yet in Martha's case it appears that she was not willing to promote student dialogue despite Tom's repeated suggestions and offers of assistance. While she may have implemented this new practice and rejected it as not having led to positive student outcomes, given the many other changes that her practice underwent, this appears unlikely.

A more plausible explanation results by also applying Guskey's criteria to a teacher's choice of what new practices to use rather than just the results of use of the new practice. Martha's beliefs about management and control of the classroom may have created the perception that this new practice would not lead to positive student outcomes and thus was not implemented. However, as a result of her changed beliefs, promotion of student dialogue may have been perceived as leading to positive student outcomes and was subsequently implemented.

In contrast to Sofia who appears to have perceived the practices that she was being asked to implement as leading to positive student outcomes, Fred likely did not have this perception regarding the new practices. However, as he did attempt some of the new practices due to Tom's assistance, he may also have perceived only the difficulties that students and he encountered when implementing the SWH approach rather than any positive outcomes. As a result he appears to have abandoned use of the approach.

Therefore, rather than viewing change in practice and belief as a linear process with one always preceding the other, a more accurate description may be that a cyclic relationship exists where change in practice leads to change in belief that leads to change in practice. In addition, this relationship is likely dynamic in that practices and beliefs actually are changing at the same time.

Thus it appears that both teachers' practice and beliefs must be targeted for change; although as is true of educating students, the beliefs and practices of the individual will determine if, and in which, emphasis should be placed. For those teachers such as Fred whose beliefs are generally inconsistent with the practices required to implement inquiry, greater focus on change in beliefs may be required. As their beliefs change so that some of the new practices are more consistent with their beliefs, then change in practice should follow. For those teachers like Martha whose beliefs are more consistent with use of some of the new practices required, an individual plan targeting use of those practices could be developed. As these practices are implemented, the teachers beliefs should be monitored for change such that additional practices that are consistent with the changed beliefs can be initiated. For the minority of teachers like Sofia who exhibit beliefs that are highly consistent with the use of inquiry and demonstrate more effective practice, the goal may be further refinement of both practice and beliefs resulting in mastery teaching.

Application of in-class professional development

The suggestion that teachers may require improvement plans tailored to their unique combination of practices and beliefs provides further reason to move from the 'one size fits all' approach of the various training models and towards more individualized support. One method that may useful in this endeavor is to employ in-class support systems using retired

teachers such as described in this study. Although Tom did not actively monitor and attempt to change the teachers' beliefs, the support provided regarding the teachers' practice was individualized to the extent possible. With the addition of measures designed to take teachers beliefs into account, this form of professional development support could provide a means of tailoring individualized plans to teachers including the monitoring of progress and adaptation of plans as required. This form of support might also increase the numbers of teachers who receive professional development support as the cost may be relatively low in comparison to other programs.

The future role for professional development

Finally, the results of this study bring into question what the purpose of professional development should be in the twenty first century. While the reform efforts of the 1960s focused on providing teachers with the skills and knowledge needed to effectively implement inquiry that had not been part of their preservice preparation, forty years later the same situation appears to exist. As reflected in Fred's case and the results of larger scale research (Pasley et al., 2004), the majority of teachers still design and implement low quality lessons. In addition, although Martha now appears to have moderately effective practice, progress has been slow as she was now in her twelfth year of teaching science. While this improved practice is laudable, for many years her students apparently received low quality instruction.

Thus, even though progress has been made in developing more effective professional development programs, the process is still slow, resulting in low quality instruction for many students with no guarantee that a teacher will improve their practice. In contrast to the current role professional development plays in attempting to promote major changes in teachers practice, students would likely receive consistently higher quality instruction if teachers

entered the classroom capable of implementing moderately to highly effective lessons as Sofia did. When teachers are provided with effective preservice preparation, professional development then would serve more to "help teachers refine their vision of effective instruction and use it to guide their lesson design and implementation" (Pasley et al., 2004, p. 10).

Limitations

There are a number of limitations to be acknowledged and addressed regarding the present study. Many of these limitation arise from the distance that separated the researcher from the participating teachers, including lack of on-site participation by the researcher, issues relating the use of remote observation techniques, lack of pre and post observation interviews, and difficulties in collecting the appropriate data. Other limitations involve lack of observational data from before this study, the limited number of interviews and possible biases involving this researcher and Tom.

The distance separating this researcher and the participants created several limitations. First, the researcher was not actively involved in working with the teachers and thus does not have firsthand knowledge about the intricate workings of the professional development they were provided and the teachers' experience implementing the SWH approach. Second, the researcher was not able to conduct on-site observations and thus had to utilize video taped lessons for analysis. While there are many advantages to the use of videotape, especially in conjunction with on-site observation, the classroom set up and camera position made it difficult to hear teacher-student interactions especially during Sofia's lesson three and four involving small group work and making it difficult to accurately determining the state of her

pedagogical practices at that time. Third, it was not possible to conduct pre and post-class interviews to provide information about the context of the lessons within the unit.

There are also several limitations relating to the data that was collected. First, the proposed plan was to conduct videotaped observations of each teacher approximately every five weeks to use for analysis of their pedagogical practice and any changes that may have occurred, however this schedule was not maintained. Thus, there were only five observations recorded for each teacher during the study. This can be problematic as other researchers have suggested that even eight observations do not provide an accurate picture of what occurs in the classroom (Tobin and Fraser, 1990). Second, creating a greater limitation is that the observations did not occur at evenly spaced times. For example, in Martha's case, while one lesson was videotaped early in the first semester, all subsequent lessons were taped within a three-month period in the second semester of school, with two of the five lessons occurring within a three-week period. It is very unlikely that change will occur over such a short period. Third, while the observations of Sofia were more spread out over time, the third and fourth observations were only approximately fifteen minutes and were limited due to technical issues previously mentioned. Therefore, the accuracy of the observations for these two lessons was reduced.

The lack of research data on the teachers practice from years prior is also a limitation, especially in Martha's case. While the original intent of this study was to only use evidence from the examination of the videotapes of the teachers for changes in their practice, the interviews provided an additional source of evidence. While this can prove beneficial in triangulating changes that are observed in the lessons, it also creates a limitation, as many of the changes teachers reported could not be confirmed by observation. This was especially

evident in Martha's case as many of the changes that are reported were in relation to her practice in years before this study occurred. This study does not include observational data prior to the year in which this study was conducted and thus cannot document these changes in pedagogical practice Martha believes to have occurred. However, in some cases it is possible to confirm the resulting practice from classroom observation and was noted when possible. For example, she reported using many additional activities and was observed engaging the students in activities during each observation. In addition, Martha did not claim to be promoting student dialogue despite Tom's repeated suggestions, suggesting that her reports are accurate.

While the use of interviews with the teachers provided valuable insight into their beliefs and changes that may have occurred in practice, a limitation in this study occurs as the interviews were not conducted until approximately five months into the study. While the teachers did provide short written responses to several questions designed to elicit their beliefs about teaching and learning early into the study, this does not provide the in-depth information that interviews can provide. This limits the ability of this researcher to determine what the teachers' beliefs were early in the study and thus difficult to determine the amount of change. In addition, while two interviews were conducted with Sofia and Fred, a second interview with Martha was not possible due to scheduling issues at the end of the school year.

The mode in which the professional development was provided produces a limitation in this study. Tom was not required to detail actions that he took with the teachers as part of the support he provided, thus for this study it was assumed that Tom provided support in the

manner requested by Dr. Hand. In addition, Tom was not interviewed in depth to determine biases he had that may influence the results of this study, creating a further limitation.

An additional limitation of this study is that data analysis and interpretation of the results was conducted by this researcher alone. Consequently, this researcher's biases may have resulted in an inaccurate portrayal and interpretation of the teachers' experiences while implementing the SWH approach.

Implications

Several implications for future research arise from this current study. These include further elucidation of the relationship between practice and beliefs and how this affects teachers' ability to implement new practices during professional development programs, examination of the impact of integrating science and language arts instruction on student achievement, and additional studies on the unique form of professional development as described in this study.

As the changes in practice that a teacher is willing to voluntarily undertake may be influenced by their beliefs, further research into the relationship between practice and belief and the impact this has on teacher change is needed. For example, research could be conducted where teachers' beliefs are documented and individualized plans developed recommending new practices to implement that appear consistent with each teacher's beliefs. Professional development support personnel could then assist each teacher in developing the appropriate skills and knowledge. Teachers would also be provided with additional opportunities to reflect upon their beliefs and the consistency that these are reflected in practices. Routine monitoring of changes in practice and belief would occur in order to modify the individual plans as required.

A surprising implication of the results of this study arises from the integration of language arts and science instruction that occurred in Martha's practice. The integration of these two subjects that she had been trained to teach separately provided additional instructional time for both subjects, and appeared to benefit students as traditional language lessons now involved reading books to develop answers to their questions about science concepts. In addition, Martha believed that students also benefited by the emphasis on proper grammar and language during science instruction. The potential positive outcomes suggest that promoting this integration of language and science as part of the SWH approach may be useful. For example, many elementary teachers may teach very little science, viewing this as taking away time from language instruction. However, by integrating the two subjects, teachers may still provide language instruction throughout the school day while also engaging students in the study of science concepts. In addition to the possible positive impact on providing professional development for teachers, it would also be useful to conduct research examining possible impacts on student achievement from the integration of language arts and science.

The unique form of professional development involving in-class support provided in this study should also be studied on a larger scale. An interesting study would involve using the book currently being written to assist teachers with using the SWH approach. While originally intended for teachers implementing the SWH approach on their own or in conjunction with other teachers, in-class support as supplied in this study may provide a low-cost effective means to increase the effectiveness that teachers are able to use the approach. Additional studies with this unique form of professional development in assisting teachers to implement other research based teaching and learning strategies could be conducted.

APPENDIX A

1. How long have you been teaching (in total and science)?

2. Describe in general your preparation for teaching, including both the education and science courses you took and where this occurred.

3. Please provide a brief description of any other professional development programs have you been involved in. What impact, if any, do you feel these have had on your teaching?

4. Regarding the unit that you have just completed using the SWH approach:
    a. What was the big idea(s) for the unit?,
    b. How many days did the unit cover?,
    c. Please provide a brief description of the activities that the students used the SWH template for.

5. Tell me about how your experience implementing the SWH has gone so far. After you have provided whatever response you wish to make, we may also discuss the following areas:
    a. In your estimation, what have been the successes you have had?
    b. What have been the challenges in implementing the SWH?
    c. What aspects of your teaching do you feel have changed as a result of using the SWH approach?,
    d. What aspects of your teaching do you feel that you need to develop in order to better implement the SWH approach?

6. Imagine that you are trying to explain the SWH approach to another teacher that is interested in using it. What would you tell them about it?

7. Describe your view of how you believe students learn.

8. Describe what you see as you role as a teacher in student learning.

9. Imagine this scenario, it is parent teacher conference night and a parent approached you complaining that the SWH approach that you are using is not an effective way for students to learn. They suggest that you focus more on what is in the textbook and use the labs that come with it. How could you explain to them why you are using this approach?

10. Please describe the metaphor for teaching that you have at the present time and discuss how this has changed from previous metaphors.

11. What are the goals that you have for students?

12. What are the reasons that you have for why students need to learn science.

APPENDIX B

B. Capsule Description of the Quality of the Lesson

In this final rating of the lesson, consider all available information about the lesson, its context and purpose, and your own judgment of the relative importance of the ratings you have made. Select the capsule description that best characterizes the lesson you observed. Keep in mind that this rating is *not* intended to be an average of all the previous ratings, but should encapsulate your overall assessment of the quality and likely impact of the lesson. Please provide a brief rationale for your final capsule description of the lesson in the space provided.

- ○ **Level 1: Ineffective Instruction**
  There is little or no evidence of student thinking or engagement with important ideas of mathematics/science. Instruction is *highly unlikely* to enhance students' understanding of the discipline or to develop their capacity to successfully "do" mathematics/science. Lesson was characterized by either (select one below):

  - ○ **Passive "Learning"**
    Instruction is pedantic and uninspiring. Students are passive recipients of information from the teacher or textbook; material is presented in a way that is inaccessible to many of the students.

  - ○ **Activity for Activity's Sake**
    Students are involved in hands-on activities or other individual or group work, but it appears to be activity for activity's sake. Lesson lacks a clear sense of purpose and/or a clear link to conceptual development.

- ○ **Level 2: Elements of Effective Instruction**
  Instruction contains some elements of effective practice, but there are *serious problems* in the design, implementation, content, and/or appropriateness for many students in the class. For example, the content may lack importance and/or appropriateness; instruction may not successfully address the difficulties that many students are experiencing, etc. Overall, the lesson is *very limited* in its likelihood to enhance students' understanding of the discipline or to develop their capacity to successfully "do" mathematics/science.

- ○ **Level 3: Beginning Stages of Effective Instruction** (Select one below.)
  ○ Low 3 ○ Solid 3 ○ High 3
  Instruction is purposeful and characterized by quite a few elements of effective practice. Students are, at times, engaged in meaningful work, but there are *weaknesses*, ranging from substantial to fairly minor, in the design, implementation, or content of instruction. For example, the teacher may short-circuit a planned exploration by telling students what they "should have found"; instruction may not adequately address the needs of a number of students; or the classroom culture may limit the accessibility or effectiveness of the lesson. Overall, the lesson is *somewhat limited* in its likelihood to enhance students' understanding of the discipline or to develop their capacity to successfully "do" mathematics/science.

- ○ **Level 4: Accomplished, Effective Instruction**
  Instruction is purposeful and engaging for most students. Students actively participate in meaningful work (e.g., investigations, teacher presentations, discussions with each other or the teacher, reading). The lesson is well-designed and the teacher implements it well, but adaptation of content or pedagogy in response to student needs and interests is limited. Instruction is *quite likely* to enhance most students' understanding of the discipline and to develop their capacity to successfully "do" mathematics/science.

- ○ **Level 5: Exemplary Instruction**
  Instruction is purposeful and all students are highly engaged most or all of the time in meaningful work (e.g., investigation, teacher presentations, discussions with each other or the teacher, reading). The lesson is well-designed and artfully implemented, with flexibility and responsiveness to students' needs and interests. Instruction is *highly likely* to enhance most students' understanding of the discipline and to develop their capacity to successfully "do" mathematics/science.

Please provide your rationale for the capsule rating:

APPENDIX C

Modified *SATIC*[*] Coding Sheet

Teacher: _____ Course: _____ Date: ___/____/____

Lesson goals: _____

Lesson objectives: _____

Teacher Behaviors	1st five minutes	2nd five minutes	3rd five minutes	Total
Initiatory (talking)				
1. Lectures or gives directions				
2. Makes statement or asks rhetorical question				
Initiatory (questioning)				
3. a) yes/no question				
b) short-answer question				
c) thought-provoking short-answer question				
4. Extended-answer question				
Responding (teacher-centered)				
5. Rejects student comment				
6. Acknowledges student comment				
7. Confirms student comment				
8. Repeats student comment				
9. Clarifies or interprets what student said				
10. Answers student question				
Responding (student-centered)				
11. Asks student to clarify or elaborate				
12. Uses student question or idea				
Non-verbal Behaviors				
13. a) Inappropriate wait-time I				
b) Inappropriate wait-time II				
14. Passive non-verbal behaviors				
15. Annoying mannerisms				

[*] A teacher behavior assessment devised by Dorothy M. Schlitt and Michael Abraham (modified by Michael P. Clough)

BIBLIOGRAPHY

Abraham, M. R. (1998). The learning cycle approach as a strategy for instruction in science. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education*. (pp. 513-524). Dordrecht ; Boston: Kluwer Academic.

Abraham, M. R. & Schlitt, D. M. (1973). Verbal interaction: A means for self evaluation. *School Science and Mathematics*, *73*(8), 678-686.

Akkus, R., Gunel, M., & Hand, B. (in press). Comparing an inquiry-based approach known as the science writing heuristic to traditional science teaching practices: Are there differences? *International Journal of Science Education*.

Alberts, B. (2000). Some thoughts of a scientist on inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science*. (pp. 15-19). Washington, D.C.: American Association for the Advancement of Science.

Alvermann, D. E. & Hayes, D. A. (1989). Classroom discussion of content area reading assignments: An intervention study. *Reading Research Quarterly*, *24*(3), 305-334.

Alvermann, D. E., O'Brien, D. G., & Dillon, D. R. (1990). What teachers do when they say they're having discussions of content area reading assignments: A qualitative analysis. *Reading Research Quarterly*, *24*(4), 296-322.

American Association for the Advancement of Science. (1990). *Science for all americans.* New York: Oxford University Press.

Anderson, R. D. (1996). *Study of curriculum reform. [Volume I: Findings and conclusions.] studies of education reform.* Washington, D.C.: U.S. Government Printing Office.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1-12.

Anderson, R. D. & Helms, J. V. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching*, *38*(1), 3-16.

Anderson, R. D. & Mitchner, C. P. (1994). Research on science teacher education. In D. L. Gabel, Ed. (Ed.), *Handbook of research on science teaching and learning*. (pp. 3-44). New York: MacMillan.

Arora, A. G., Kean, E., & Anthony, J. L. (2000). An interpretive study of a teacher's evolving practice of elementary school science. *Journal of Science Teacher Education*, *11*(2), 155-72 May.

Baker, D. R. & Piburn, M. D. (1997). *Constructing science in middle and secondary school classrooms.* Boston: Allyn and Bacon.

Ball, D. L. & Cohen, D. K. (1996). Reform by the book: What is--or might be--the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher*, *25*(9), 6-8,14.

Beck, J., Czerniak, C. M., & Lumpe, A. T. (2000). An exploratory study of teachers' beliefs regarding the implementation of constructivism in their classrooms. *Journal of Science Teacher Education*, *11*(4), 323-343.

Bell, B. (2005). Pedagogies developed in the learning in science projects and related theses. *International Journal of Science Education*, *27*(2), 159-182.

Bloom, B. S., Englehart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives. Handbook I: Cognitive domain.* New York: David McKay.

Blosser, P. E. (1991). *How to ask the right questions.* Washington, DC: NSTA Press.

Blumenfeld, P. C., Krajcik, J., Marx, R. W., & Soloway, E. (1994). Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction. *Elementary School Journal*, *94*(5), 539-551.

Bonnstetter, R. J. (1998). Inquiry: Learning from the past with an eye on the future. *Electronic Journal of Science Education*, *3*(1).

Borko, H. & Putman, R. T. (1995). Expanding a teacher's knowledge base: A cognitive psychological perspective on professional development. In T. R. Guskey & M. Huberman (Eds.), *Professional development in education: New paradigms and practices*. (pp. 35-65). New York: Teachers College Press.

BouJaoude, S. (2000). Conceptions of science teaching revealed by metaphors and by answers to open-ended questions. *Journal of Science Teacher Education*, *11*(2), 173-186.

Boulton-Lewis, G. M., Smith, D. J. H., McCrindle, A. R., Burnett, P. C., & Campbell, K. J. (2001). Secondary teachers' conceptions of teaching and learning. *Learning and Instruction*, *11*, 35-51.

Bransford, J. (2000). *How people learn : Brain, mind, experience, and school* (Expanded ed.). Washington, D.C: National Academy Press.

Brophy, J. & Good, T. L. (1986). Teacher behavior and student achievement. In M. C. Wittrock (Ed.), *Handbook of research on teaching*. (3rd ed., pp. 328-375). New York: MacMillan Publishing Company.

Bryan, L. A. (2003). Nestedness of beliefs: Examining a prospective elementary teachers' belief system about science teaching and learning. *Journal of Research in Science Education*, *40*(9), 835-868.

Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science*. (pp. 15-19). Washington, D.C.: American Association for the Advancement of Science.

Bybee, R. W. & Ben-Zvi, N. (1998). Science curriculum: Transforming goals to practices. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education*. (pp. 487-498). Dordrecht ; Boston: Kluwer Academic.

Carter, K. (1990). Meaning and metaphor: Case knowledge in teaching. *Theory into Practice*, *29*(2), 109-115.

Clark, R. L., Clough, M. P., & Berg, C. A. (2000). Modifying cookbook labs. *The Science Teacher*, *67*(7), 40-43.

Clough, M. P. (2002). Using the laboratory to enhance student learning. In R. W. Bybee (Ed.), *Learning science and the science of learning*. (pp. 85-94). Washington, D.C.: National Science Teachers Association.

Colburn, A. (2000). An inquiry primer. *Science Scope,* 42-44.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, *37*(9), 916-937.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Education*, *44*(4), 586-612.

Cronin-Jones, L. L. (1991). Science teacher beliefs and their influence on curriculum implementation: Two case studies. *Journal of Research in Science Teaching*, *28*(3), 235-50 Mar.

Cuban, L. (1988). Constancy and change in schools (1880s to the present). In P. W. Jackson (Ed.), *Perspectives on research and practice.* Chicago: McCutchan Publishing Corporation.

Cunningham, R. T. (1987). What kind of question is that? In W. W. Wilen (Ed.), *Questions, questioning techniques, and effective questioning*. (pp. 67-93). Washington, DC: National Education Association.

Darling-Hammond, L. & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597-604.

Davis, K. S. (2003). "Change is hard": What science teachers are telling us about reform and teacher learning of innovative practices. *Science Education*, *87*(1), 3-30.

DeBoer, G. E. (1991). *A history of ideas in science education.* New York: Teachers College Press.

Dewey, J. (1910). *How we think.* Lexington, Mass.: D.C. Heath.

Dilley, P. (2000). Conducting successful interviews: Tips for intrepid research. *Theory into Practice*, *39*(3), 131-137.

Downing, J. E. & Gifford, V. (1996). An investigation of preservice teachers' science process skills and questioning strategies used during a demonstration science discovery lesson. *Journal of Elementary Science Education*, *8*(1), 64-75.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. H. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5-12.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*, 287-312.

Driver, R. & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education*, *13*, 105-122.

Duschl, R. A. & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment*, *4*(1), 37-73.

Erickson, F. (1998). Qualitative research methods for science education. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education*. (pp. 1155-1173). Dordrecht ; Boston: Kluwer Academic.

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research and Development*, *53*(4), 25-39.

Esterberg, K. G. (2002). *Qualitative methods in social research.* Boston: McGraw-Hill.

Flick, L. B. (1995). *Complex instruction in complex classrooms: A synthesis of research on inquiry teaching methods and explicit teaching strategies*. Paper presented at the National Association for Research in Science Teaching 1995 Annual Meeting, San Francisco, CA.

Flick, L. B. (2000). Cognitive scaffolding that fosters scientific inquiry in middle level science. *Journal of Science Teacher Education*, *211*, 109-129.

Flick, L. B. & Dickinson, V. L. (1997). *Teacher intentions, teaching practice, and student perceptions of inquiry-oriented teaching*. Paper presented at the National Association for Research in Science Teaching, Oak Brook, IL.

Fradd, S. H. & Lee, O. (1999). Teachers' roles in promoting science inquiry with students from diverse language backgrounds. *Educational Researcher*, *28*(6), 14-20, 42.

Fraser, B. J. (1998). Research on classroom and school climate. In D. L. Gabel, Ed. (Ed.), *Handbook of research on science teaching and learning*. (pp. 493-?). Washington, D.C.: National Science Teachers Association.

Fullan, M. (2001). *The new meaning of educational change.* New York: Teachers College Press.

Gall, M. (1984). Synthesis of research on teachers' questioning. *Educational Leadership*, *42*(3), 40-47.

Gall, M. & Rhody, T. (1987). Review of research on questioning techniques. In W. W. Wilen (Ed.), *Questions, questioning techniques, and effective teaching*. (pp. 23-48). Washington, DC: National Education Association.

Gallagher, J. J. & Tobin, K. (1987). Teacher management and student engagement in high school science. *Science Education*, *471*, 535-555.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.

Garnett, P. J. & Tobin, K. (1988). Teaching for understanding: Exemplary practice in high school chemistry. *Journal of Research in Science Teaching*, *26*(1), 1-14.

Gess-Newsome, J. (2001). The professional development of science teachers for science education reform: A review of the research. In J. Rhoton & P. Bowers (Eds.), *Professional development: Planning and design*. (pp. 91-100). Arlington, VA: NSTA Press.

Gess-Newsome, J. (2003). *Implications of the definitions of knowledge and beliefs on research and practice in science teacher education*. Paper presented at the National Association for Research in Science Teaching, Philadelphia, PA.

Glesne, C. (1998). *Becoming qualitative researchers: An introduction* (2nd ed.). New York: Longman.

Guskey, T. R. (2002). Professional development and teacher change. *Teachers and Teaching: theory and practice*, *8*(3/4), 381-391.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher*, *515*, 5-12.

Hancock, E. S. & Gallard, A. J. (2004). Preservice science teachers' beliefs about teaching and learning: The influence of k-12 field experience. *Journal of Science Teacher Education*, *15*(4), 281-291.

Hand, B. & Treagust, D. F. (1997). Monitoring teachers' referents for classroom practice using metaphors. *International Journal of Science Education*, *19*(2), 183-192.

Hand, B., Wallace, C., & Yang, E.-M. (2004). Using a science writing heuristic to enhance learning outcomes from laboratory activities in seventh-grade science: Quantitative and qualitative aspects. *International Journal of Science Education*, *26*(2), 131-149.

Haney, J. J., Lumpe, A. T., Czerniak, C. M., & Egan, V. (2002). From beliefs to actions: The beliefs and actions of teachers implementing change. *Journal of Science Teacher Education*, *13*(3), 171-187.

Harms, N. C. & Kahl, S. (1980). *Project synthesis: Final report to the national science foundation.* Boulder, CO: University of Colorado.

Harms, N. C. & Yager, R. E. (1981). *What research says to the science teacher, volume 3. Science education information report.* Washington, D.C.: National Science Teachers Association.

Haury, D. L. (1993). Teaching science through inquiry. *ERIC/CSMEE Digest,* March. (ED359048).

Hewson, P. W. & Hewson, M. G. A. B. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science*, *13*, 1-13.

Hoetker, J. & Albrand, W. P. (1969). The persistence of the recitation. *American Educational Research Journal*, *6*(2), 145-167.

Hohenshell, L., Hand, B. M., & Rudd, J. A., II (2002). *Using writing to learn strategies to demonstrate learning in cell biology*. Paper presented at the International conference on Ontological, Epistemological, Linguistics and Pedagogical Considerations of Language and Science Literacy: Empowering Research and Informing Instruction, Victoria, BC, Canada.

Horizon Research, Inc. (2000). *Validity and reliability information for the lsc classroom observation protocol.* Chapel Hill, NC: Horizon Research, Inc.

Horizon Research, Inc. (2004). *2004-05 local systemic change classroom observation protocol.* Chapel Hill, NC: Horizon Research, Inc.

Huberman, A. M. & Miles, M. B. (1984). *Innovation up close: How school improvement works.* New York: Plenum Press.

Jaeger, R. M. (1993). *Live vs. Memorex: Psychometric and practical issues in the collection of data on teachers' performances in the classroom*. Paper presented at the Annual Meeting of the American Educational Research Association, Atlanta, GA.

Johnson, C. C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics*, *106*(3), 150-161.

Kagan, D. M. (1992). Implications of research on teacher belief. *Educational Psychologist*, *27*(1), 65-90.

Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the goldilocks principle. *Review of Educational Research*, *60*(3), 419-469.

Kang, N.-H. & Wallace, C. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals and practices. *Science Education*, *89*, 140-165.

Karplus, R. (1975). The learning cycle. In F. Collea (Ed.), *Workshop on physics teaching and the development of reasoning.* Stonybrook, NY: American Association of Physics.

Kelly, M. P. & Staver, J. R. (2005). A case study of one school system's adoption and implementation of an elementary science program. *Journal of Research in Science Teaching*, *41*(1), 25-52.

Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching*, *37*(7), 676-690.

Keys, C. W. & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Education*, *38*(6), 631-645.

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching*, *36*(10), 1065-1084.

Keys, C. W. & Kennedy, V. (1999). Understanding inquiry science teaching in context: A case study of an elementary teacher. *Journal of Science Teacher Education*, *10*(4), 315-33 Nov.

Keys, C. W., Yang, E. M., Hand, B., & Hohenshell, L. (2001). *Using a science writing heuristic as a tool to enhance learning from laboratory activities in seventh grade science: Quantitative and qualitative outcomes*. Paper presented at the Annual Meeting National Association for Research in Science Teaching, St. Louis, MO.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75-86.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping middle grade science teachers learn project-based instruction. *The Elementary School Journal*, *94*(5), 483-497.

Krathwohl, D. R. (1997). *Methods of educational and social science research: An integrated approach* (2nd ed.). New York: Longman.

Kumar, D. D. (1993). Effective instructional strategies in science revisited. *American Secondary Education*, *21*(3), 9-14.

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching*, *41*(10), 1021-1043.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex Publishing Corporation.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundy, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics.* Thousand Oaks: Corwin Press, Inc.

Loucks, S. & Pratt, H. (1979). A concerns-based approach to curriculum change. *Educational Leadership*, *37*(3), 212-215.

Luft, J. A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experiences secondary science teachers. *International Journal of Science Education*, *23*(5), 517-534.

Luft, J. A. & Pizzini, E. L. (1998). The demonstration classroom in-service: Changes in the classroom. *Science Education*, *82*, 147-162.

Luft, J. A., Roehrig, G. H., & Patterson, N. G. (2003). Contrasting landscapes: A comparison of the impact of different induction programs on beginning secondary teachers' practices, beliefs, and experiences. *Journal of Research in Science Education*, *40*(1), 77-97.

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory, and practice. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education*. (pp. 393-441). New Jersey: Lawrence Erlbaum Associates.

Martens, M. L. (1999). Productive questions: Tools for supporting constructivist questioning. *Science and Children*, *May*, 24-27, 53.

Martin, A. & Hand, B. (2007). *Promoting elements of argument in a fifth grade classroom.* Paper presented at the Annual International Meeting of the Association for Science Teacher Education, Clearwater Beach, FL.

Marx, R. W., Blumenfeld, P. C., Krajcik, J., Blunk, M., Crawford, B. A., Kelly, B., et al. (1994). Enacting project-based science: Experiences of four middle grade teachers. *The Elementary School Journal*, *94*(5), 517-538.

Marx, R. W., Blumenfeld, P. C., Krajcik, J., & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal*, *97*(4), 341-358.

Maxwell, J. A. (2002). Understanding and validity in qualitative research. In M. Huberman & M. B. Miles (Eds.), *The qualitative researchers companion*. (pp. 37-64). Thousand Oaks: Sage Publications.

McLaughlin, M. W. & Talbert, J. E. (1993). *Contexts that matter for teaching and learning: Strategic opportunities for meeting the nation's educational goals.* Stanford University.

Merriam, S. B. (2002). *Qualitative research in practice: Examples for discussion and analysis* (The Jossey-Bass higher and adult education series). San Francisco: Jossey-Bass.

Minstrell, J. (2000). Implications for teaching and learning inquiry: A summary. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science*. (pp. 471-496). Washington, D.C.: American Association for the Advancement of Science.

Murray, K. & MacDonald, R. (1997). The disjunction between lecturers' conceptions of teaching and their claimed educational practice. *Higher Education*, *33*, 331-349.

National Commission on Teaching & America's Future. (1996). What matters most: Teaching for america's future. Report of the national commission on teaching & america's future., 161.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: National Council of Teachers of Mathematics.

National Research Council. (2000). *Inquiry and the national science education standards : A guide for teaching and learning.* Washington, D.C: National Academy Press.

National Research Council. (2001). The power of video technology in international comparative research in education*.,* 44.

National Research Council. (1996). *National science education standards.* Washington, DC.: National Academy of Sciences - National Research Council.

Norton-Meier, L., Nelson, S., Hockenberry, L., & Wise, K. (2007). Transforming pedagogy: Embedding language practices in elementary classrooms. In B. Hand (Ed.), *Science inquiry and language: The case for the science writing heuristic (swh).* Rotterdam, the Netherlands: Sense Publishers.

Olson, J. K. & Clough, M. P. (2004). What questions do you have? In defense of general questions: A response to Croom. *Teachers College Record* Retrieved May 5, 2006,

Omar, S. (2004). *Inservice teachers' implementation of the science writing heuristic as a tool for professional growth.* Unpublished dissertation, Iowa State University, Ames, IA.

Omar, S., Hand, B., & Greenbowe, T. J. (2002). *Teaching assistants facilitating conceptual understanding in an introductory chemistry laboratory course using the science writing heuristic: Quantitative and qualitative aspects*. Paper presented at the International Conference on Ontological, Epistemological, Linguistics and Pedagogical Considerations of Language and Science Literacy: Empowering Research and Informing Instruction, Victoria, BC, Canada.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307-332.

Pasley, J. D., Weiss, I. R., Shimkus, E. S., & Smith, P. S. (2004). Looking inside the classroom: Science teaching in the united states. *Science Educator*, *13*(1), 1-12.

Patterson, J. L. & Czajkowski, T. J. (1979). Implementation: Neglected phase in curriculum change. *Educational Leadership*, *37*(3), 204-206.

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* Newbury Park, CA: Sage Publications.

Peers, C. S. E., Diezmann, C. M., & Watters, J. J. (2003). Supports and concerns for teacher professional growth during the implementation of a science curriculum innovation. *Research in Science Education*, *33*(1), 89-110.

Penick, J. E., Crow, L. W., & Bonnstetter, R. J. (1996). Questions are the answer. *The Science Teacher*, *63*(Jan), 27-29.

Peterson, P. L., Fennema, E., Carpenter, T. P., & Loef, M. (1989). Teachers' pedagogical content beliefs in mathematics. *Cognition and Instruction*, *6*(1), 1-40.

Pinto, R. (2005). Introducing curriculum innovations in science: Identifying teachers' transformations and the design of related teacher education. *Science Education*, *89*, 1-12.

Plowman, L. (1999). Using video for observing interaction in the classroom. *SCRE Spotlights*, *72*, 1-4.

Porter, A. C. (1986). From research on teaching to staff development: A difficult step. *The Elementary School Journal*, *87*(2), 158-164.

Porter, A. C., Garet, M. S., Desimone, L. M., & Birman, B. F. (2003). Providing effective professional development: Lessons from the Eisenhower program. *Science Educator*, *12*(1), 23-34.

Porter, A. C., Garet, M. S., Desimone, L., Yoon, K. S., & Birman, B. F. (1999). Does professional development change teaching practice? Results from a three-year study.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211-227.

Prawat, R. S. (1992). Teachers' beliefs about teaching and learning: A constructivist perspective. *American Journal of Education*, *100*(3), 354-395.

Richardson, V. (1998). How teachers change: What will lead to change that most benefits student learning. *Focus on Basics*, *2*(C), 1-10.

Richardson, V., Anders, P., Tidwell, D., & Lloyd, C. (1991). The relationship between teachers' beliefs and practices in reading comprehension instruction. *American Educational Research Journal*, *28*(3), 559-586.

Richardson, V. & Placier, P. (2001). Teacher change. In V. Richardson (Ed.), *Handbook of research on teaching*. (4th ed., pp. xiii, 1278 p). Washington, D.C: American Educational Research Association.

Ritchie, S. M. (1994). Metaphor as a tool for constructivist science teaching. *International Journal of Science Education*, *16*(3), 293-303.

Roehrig, G. H. & Kruse, R. A. (2005). The role of teachers' beliefs and knowledge in the adoption of reform-based curriculum. *School Science and Mathematics*, *105*(8), 412-422.

Roschelle, J. (1999). Choosing and using video equipment for data collection. In A. E. Kelly & R. A. Lesh (Eds.), *Handbook of research design in mathematics and science education*. (pp. 709-729). London: Lawrence Erlbaum Associates.

Rowe, M. B. (1974). Wait-time and rewards as instructional variables, their influence on language, logic and fate control: Part one-wait-time. *Journal of Research in Science Teaching*, *11*(2), 81-94.

Rowe, M. B. (1986). Wait-time: Slowing down may be a way of speeding up. *Journal of Teacher Education*, *37*(1), 43-50.

Rudd, J. A., II, Greenbowe, T. J., Hand, B. M., & Legg, M. J. (2001). Using the science writing heuristic to move toward an inquiry-based laboratory curriculum: An example from physical equilibrium. *Journal of Chemical Education*, *78*(12), 1680-1686.

Saul, W. (1993). *Science workshop: A whole language approach.* Portsmouth, NH: Heinemann.

Schneider, R. M. & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education*, *13*(3), 221-245.

Schofield, J. W. (2002). Increasing the generalizability of qualitative research. In M. Huberman & M. B. Miles (Eds.), *The qualitative researchers companion*. (pp. 171-203). Thousand Oaks: Sage Publications.

Schwab, J. (1960). What do scientists do? *Behavioral Science*, *5*(1).

Schwab, J. (1966). *The teaching of science.* Cambridge, MA: Harvard University Press.

Seidman, I. (1998). *Interviewing as qualitative research : A guide for researchers in education and the social sciences.* New York: Teachers College Press.

Shymansky, J. A., Hedges, L. V., & Woodworth, G. (1990). A reassessment of the effects of inquiry-based science curricula of the 60's on student performance. *Journal of Research in Science Teaching*, *227*, 127-144.

Shymansky, J. A. & Penick, J. E. (1981). Teacher behavior does make a difference in hands-on science classrooms. *School Science and Mathematics*, *81*(5), 412-422.

Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., et al. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Education*, *36*(8), 930-954.

Simon, M. A. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for Research in Mathematics Education*, *26*(2), 114-145.

Smith, E. L. (1990). Implications of teachers' conceptions of science teaching and learning. In M. B. Rowe (Ed.), *What research says to the science teacher, volume six: The process of knowing*. (pp. 41-54). National Science Teachers Association.

Songer, N. B., Lee, H.-S., & McDonald, S. (2003). Research towards an expanded understanding of inquiry science beyond one idealized standard. *Science Education*, *87*, 490-516.

Stake, R. E. & Easley, J. A. (1978). *Case studies in science education, volume II: Design, overview and general findings.* Urbana, IL: Center for Institutional Research and Curriculum Evaluation, University of Illinois.

Stallings, J. & Krasavage, E. M. (1986). Program implementation and student achievement in a four-year Madeline Hunter follow-through project. *The Elementary School Journal*, *87*(2), 117-138.

Stigler, J., W., Gallimore, R., & Hiebert, J. (2000). Using video surveys to compare classrooms and teaching across cultures: Examples and lessons from the timss video studies. *Educational Psychologist*, *35*(2), 87-100.

Supovitz, J. A. & Turner, H. M. (2000). The effects of professional development on science teaching practice and classroom culture. *Journal of Research in Science Teaching*, *37*(9), 963-980.

Tobin, K. (1980). The effect of an extended teacher wait-time on science achievement. *Journal of Research in Science Teaching*, *17*(5), 469-475.

Tobin, K. (1986). Effects of teacher wait time on discourse characteristics in mathematics and language arts classes. *American Educational Research Journal*, *23*(2), 191-200.

Tobin, K. (1990). Changing metaphors and beliefs: A master switch for teaching? *Theory into Practice*, *29*(2), 122-127.

Tobin, K. & Fraser, B. J. (1990). What does it mean to be an exemplary science teacher? *Journal of Research in Science Teaching*, *27*(1), 3-25.

Tobin, K. & Tippins, D. J. (1996). Metaphors as seeds for conceptual change and the improvement of science teaching. *Science Education*, *80*(6), 711-730.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science: A contemporary perspective. In D. L. Gabel, Ed. (Ed.), *Handbook of research on science teaching and learning*. (pp. 45-93). Washington, D.C.: National Science Teachers Association.

Treagust, D. F. (1991). A case study of two exemplary biology teachers. *Journal of Research in Science Teaching*, *28*(4), 329-3442.

U.S. Department of Education. (1999). *Student work and teacher practices in science: A report on what students know and can do.* Washington, D.C.: National Center for Educational Statistics.

Vacc, N. N. & Bright, G. W. (1999). Elementary preservice teachers' changing beliefs and instructional use of children's mathematical thinking. *Journal for Research in Mathematics Education*, *30*(1), 89-110.

van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38*(2), 137-158.

Vogler, K. E. (2005). Improve your verbal questioning. *The Clearing House*, *79*(2), 98-103.

von Glasersfeld, E. (1983). Learning as constructive activity. In J. C. Bergeron & N. Herscovics (Eds.), *Proceedings if the 5th annual meeting if the north american group of psychology in mathematics education*. (pp. 41-101). Montreal: PME-NA.

Wallace, C. & Kang, N.-H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. *Journal of Research in Science Education*, *41*(9), 936-960.

Wallace, C. S., Hand, B., & Prain, V. (2007). *Writing and learning in the science classroom.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Weiss, I. R. (1978). *Report of the 1977 national survey of science, mathematics, and social studies education. Final report.* Washington, D.C.: U.S. Government Printing Office.

Weiss, I. R., Banilower, E. R., & Shimkus, E. S. (2004). *Local systemic change through teacher enhancement.* Chapel Hill, NC: Horizon Research, Inc.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. K. (2003). *Looking inside the classroom: A study of k-12 mathematics and science education in the united states.* Horizon Research.

Weiss, I. R. & Pasley, J. D. (2006). Scaling up instructional improvement through teacher professional development: Insights from the local systematic change initiative. *CPRE Policy Briefs,* 1-16.

Welch, W. W., Klopfer, L., Aikenhead, G., & Robinson, J. (1981). The role of inquiry in science education: Analysis and recommendations. *Science Education*, *65*(1), 33-50.

White, B. Y. & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *116*(1), 3-118.

Wilen, W. W. (1987). Effective questions and questioning: A classroom application. In W. W. Wilen (Ed.), *Questions, questioning techniques, and effective questioning*. (pp. 107-133). Washington, DC: National Education Association.

Wilen, W. W. (2001). Exploring myths about teacher questioning in the social studies classroom. *The Social Studies*, *92*(1), 26-32.

Wood, T., Cobb, P., & Yackel, E. (1991). Change in teaching mathematics: A case study. *American Educational Research Journal*, *28*(3), 587-616.

Wragg, E. C. & Brown, G. (2001). *Questioning in the primary school.* London: Routledge Falmer.

Wubbels, T. & Brekelmans, M. (1998). The teacher factor in the social climate of the classroom. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education*. (pp. 565-580). Dordrecht ; Boston: Kluwer Academic.

Yager, R. E., Hidayat, E. M., & Penick, J. E. (1988). Features which separate least effective from most effective science teachers. *Journal of Research in Science Teaching*, *25*(3), 165-177.

Yager, R. E. & Lutz, M. V. (1994). Integrated science: The importance of "how" versus "what". *School Science and Mathematics*, *94*(7), 338-346.

Yerrick, R., Parke, H., & Nugent, J. (1997). Struggling to promote deeply rooted change: The “filtering effect” of teachers’ beliefs on understanding transformational views of teaching science. *Science Education*, *81*, 137-159.